AD A146 023 A STUDY OF WEAR CHARACTERISTICS DUE TO PRESSURE FOR HYDRAULIC FIXED DISPL..(U) MILWAUKEE SCHOOL OF ENGINEERING WI FLUID POWER INST OCT 83 P/N-50468 1/2

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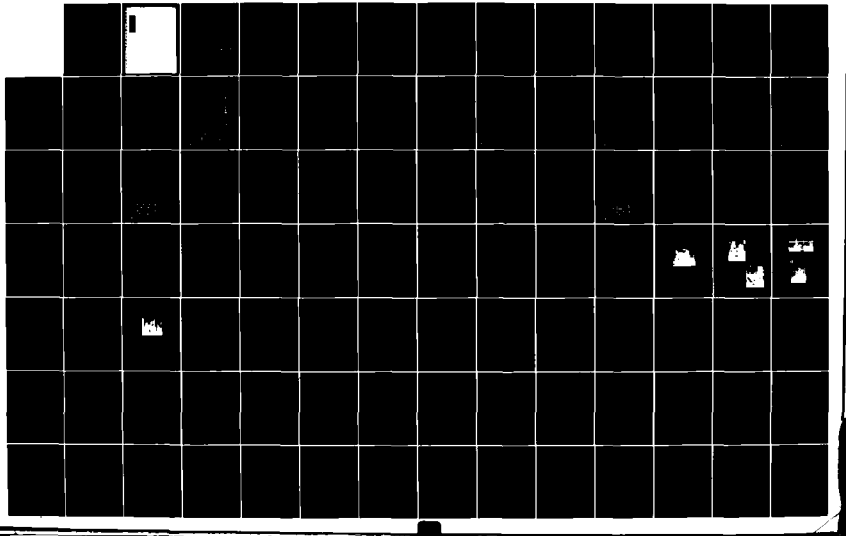

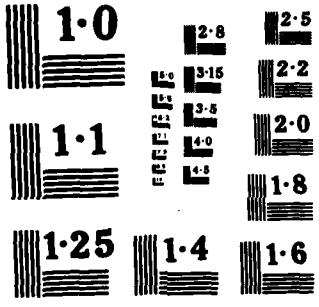
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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 50468	2. GOVT ACCESSION NO. AD-A146023
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) A Study of Wear Characteristics Due to Pressure for Hydraulic Fixed Displacement Vane Pumps	5. TYPE OF REPORT & PERIOD COVERED Sept. 1982 - Sept. 1983
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Fluid Power Institute Staff Milwaukee School of Engineering	8. CONTRACT OR GRANT NUMBER(s) DAAK70-81-C-0002 Modification P00002
9. PERFORMING ORGANIZATION NAME AND ADDRESS Milwaukee School of Engineering FPI 1025 N. Milwaukee Street Milwaukee, WI 53201	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE October 1983
	13. NUMBER OF PAGES 131
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Co ONR BRO Room 286 536 S. Clark Street Chicago, IL 60605	15. SECURITY CLASS. (of this report)
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Final Technical Report

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Hydraulic Fixed Displacement Vane Pumps
Break-In and Performance Tests
Wear Characteristics versus Pump Discharge Pressure
Wear Characteristics Analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes the results obtained in evaluating 6 pumps for wear characteristics versus pressure, and different test methods in analyzing the wear contaminates of the six test pumps using clean oil

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REPORT OF INVENTIONS AND SUBCONTRACTS

(Pursuant to "Patent Rights" Contract Clause) (See Instructions on Reverse Side)

FORM APPROVED
OMB NO. 22-R160

1. NAME AND ADDRESS OF CONTRACTOR *(Include Zip Code)*

Fluid Power Institute, Milwaukee School of Engineering
1025 North Milwaukee Street
Milwaukee, WI 53201

2. CONTRACT NUMBER

DAAK70-81-C-0002

3. TYPE OF REPORT *(Check One)*

[ ] a. INTERIM [X] b. FINAL

SECTION I - INVENTIONS *("Subject Inventions")*

4. INVENTION DATA *(Listed below are all inventions required to be reported) (If "None," so state)*

(i) NAME OF INVENTOR(S)	(ii) TITLE OF INVENTION	(iii) CONTRACTOR DISCLOSURE IDENTIFICATION NUMBER OR PATENT APPLICATION SERIAL NUMBER	(iv) CONTRACTOR ELECTS TO FILE U.S. PATENT APPLICATION		(v) CONFIRMATORY LICENSE OR ASSIGNMENT FORWARDED TO CONTRACTING OFFICER	
			YES	NO	YES	NO
NONE	NONE	NONE		X		X

SECTION II - SUBCONTRACTS *(Containing a "Patent Rights" Clause)*

5. SUBCONTRACT DATA *(Listed is information required but not previously reported for Subcontracts) (If "None," so state)*

(i) NAME AND ADDRESS OF SUBCONTRACTOR *(Include Zip Code)*	(ii) SUBCONTRACT NUMBER	(iii) SUBCONTRACT PATENT RIGHTS CLAUSE	(iv) WORK TO BE PERFORMED UNDER SUBCONTRACT	(v) SUBCONTRACT DATES	
				AWARD	COMPLETION
NONE	NONE	NONE	NONE	NONE	NONE

SECTION III - CERTIFICATION

CONTRACTOR CERTIFIES THAT PROMPT IDENTIFICATION AND TIMELY DISCLOSURE OF SUBJECT INVENTIONS PROCEDURES HAVE BEEN FOLLOWED

DATE	NAME AND TITLE OF AUTHORIZED OFFICIAL *(Print or Type)*	SIGNATURE
Sept. 1983	Thomas S. Wanke Director, Fluid Power Institute	

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SIGNATURE PAGE

The undersigned testify that to the best of their knowledge the data contained in this report was collected using instruments as described on the referenced pages and that testing and measurement procedures utilized good laboratory technique.

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APPENDICIES

INTRODUCTION

This project is undertaken to determine if the wear rate of a hydraulic vane pump can be correlated to its operating pressure. The correlation should be that the wear rate of the pump would be a linear function at low operating pressures and reach an exponential function of the pressure at some elevated pressure. According to MSOE FPI Report #50423 dated July 15, 1982 MERADCOM contract #DAAK70-81-C-0002, operating the pumps at test pressures of 115 percent of rated pressure caused normal wear of the pump.

The pumps are broken-in using two different methods to determine if the wear rate operating pressure characteristics will differ for pumps that are broken-in at 3000 PSI for three hours compared to pumps that are broken-in at 500 PSI for three hours prior to running the wear rate test.

There are two main considerations in performing the wear rate test. The first is to develop a test procedure. The test procedure consists of methods to determine the wear rate of the pump by utilizing on-hand laboratory equipment and instrumentation. The other consideration is to determine which types of oil analysis are suited to this project. Several methods are investigated and used to collect wear rate data through analysis of the pump's fluid.

PROCEDURES PRIOR TO WEAR TESTING

Six hydraulic fixed displacement vane pumps were tested in this program. Pumps from manufacturer M1 from FPI MSOE report #50423 dated July 15, 1982 MERADCOM contract #DAAK70-81-C-0002 were chosen for this test because they experienced the highest amount of wear in the endurance and durability tests. The same model pumps were used as in the previous test.

The test facility and instrumentation used to conduct the break-in, performance, and wear tests were the same as used in the vane pump test program FPI MSOE Report #50423. A description of the test facility is shown in Appendix C of this report.

Various methods of oil analysis were used to determine the wear materials from the pumps. Particle counting and sizing was done with a HIAC PC 320 "Criterion" Particle Size Analyzer and associated accessories calibrated in accordance with NFPA, ANSI, and ISO standards. These standards were also observed for providing clean sample containers, extracting samples, and performing the particle counts. The gravimetric analysis procedure is described in Appendix D of this report. The x-ray emission analysis procedure is also described in Appendix D of this report. The ferrograms were performed by an oil analysis laboratory of the US Army at Corpus Christi, Texas #SDSCC-QLS.

Three of the six pumps were broken-in in accordance with the universal break-in procedure and performance tested in accordance with NFPA T3.9.17R1. These procedures are described in Appendix A of this report.

The remaining three pumps were broken-in using the following procedure. The pumps were run at manufacturer's rated speed with an outlet pressure of 600 PSI for three hours using MIL-L-2104 grade 10 oil with 160°F inlet temperature. The following parameters were recorded at five minute intervals; inlet and outlet temperature, inlet and outlet pressure, input speed, and output flow rate. These pumps were not performance tested after the break-in procedure.

The detailed test procedure for the wear rate test is shown in Appendix B of this report.

SUMMARIZED EFFICIENCIES FOR THE THREE HOUR BREAK-IN TEST

The initial and final overall efficiencies do not necessarily represent the highest and lowest values obtained during the test. The averages shown were obtained using all the efficiencies calculated in the test, not just the initial and final.

A positive change indicates a higher overall efficiency at the end of the test, a negative change indicates a lower overall efficiency at the end of the test. Pumps A, B, and C were run at 3000 psi for three hours while pumps D, E, and F were run at 600 psi for three hours. Tabulated and graphical data are given in Appendix E of this report.

Pump #	Overall Efficiency %				Volumetric Efficiency %				Mechanical Efficiency %			
	Initial	Final	Ave.	Change	Initial	Final	Ave.	Change	Initial	Final	Ave.	Change
468A	70.3	72.4	72.2	+ 2.1	75.9	78.1	78	+ 2.2	92.6	92.7	92.6	+ .1
468B	75.7	72.1	72.5	- 3.6	81.6	77	77.7	- 4.6	92.8	93.7	93.3	+ .9
468C	76.2	75.1	75.3	- 1.1	82.2	80.9	81.1	- 1.3	92.6	92.8	92.8	+ .2
468D	75.2	74.8	74.8	- .4	94.3	94	94.1	- .3	79.7	79.5	79.4	- .2
468E	75.0	74.6	75	- .4	95.1	94.6	94.8	- .5	78.9	78.9	79	0
468F	76.3	75.1	75.8	- 1.2	95.9	95.1	95.6	- .8	79.5	79	79.3	- .5

SUMMARIZED AVERAGE VALUES OF MEASURED PARAMETERS

FOR THREE HOUR BREAK-IN TEST

Pump #	Ave. Speed RPM	Std. Dev. RPM	Ave. Flow GPM	Std. Dev. GPM	Ave. Diff. Press. PSID	Std. Dev. PSID	Ave. Input Torque IN LBS.	Std. Dev. IN LBS.
468A	2705.9	6.5	25.3	2.8	2999.6	51.8	1427.7	37.5
468B	2713.7	9.8	25.3	1.3	2992.6	25.7	1413.4	15.0
468C	2725.4	15.1	26.5	.22	3003.5	5.9	1426.6	6.2
468D	2702.9	9.9	30.5	.09	594.8	22.7	330.2	10.6
468E	2703.2	6.1	30.7	.10	591.4	6.2	329.7	5.2
468F	2707.8	5.9	31.0	.17	600.1	5.9	333.8	3.9

SUMMARIZED OVERALL EFFICIENCIES AND SIMPLE DISPLACEMENT FOR POWER CONVERSION TEST

Tabulated and graphical data for the power conversion test are given in Appendix F of this report. Definition of overall efficiency is as follows:

$$\text{Overall Efficiency} = \text{Output hp/Input hp}$$

$$\text{Output Hp} = \frac{(\text{Adjusted GPM})(\text{Target PSID})}{1714}$$

$$\text{Input Hp} = \frac{(\text{Adjusted RPM})(\text{Adjusted Torque})}{63025}$$

Pump #	Minimum Overall Efficiency %	Maximum Overall Efficiency %	Simple Displacement $in^3/rev.$
468A	39.1	80.2	2.67
468B	37.7	78.6	2.68
468C	41	79.8	2.66

TABULATED AND GRAPHICAL DATA FROM THE WEAR TEST INVESTIGATION

(Refer to Appendix B for a Detailed Procedure)

WEAR TEST INVESTIGATION DATA FOR PUMP #468A

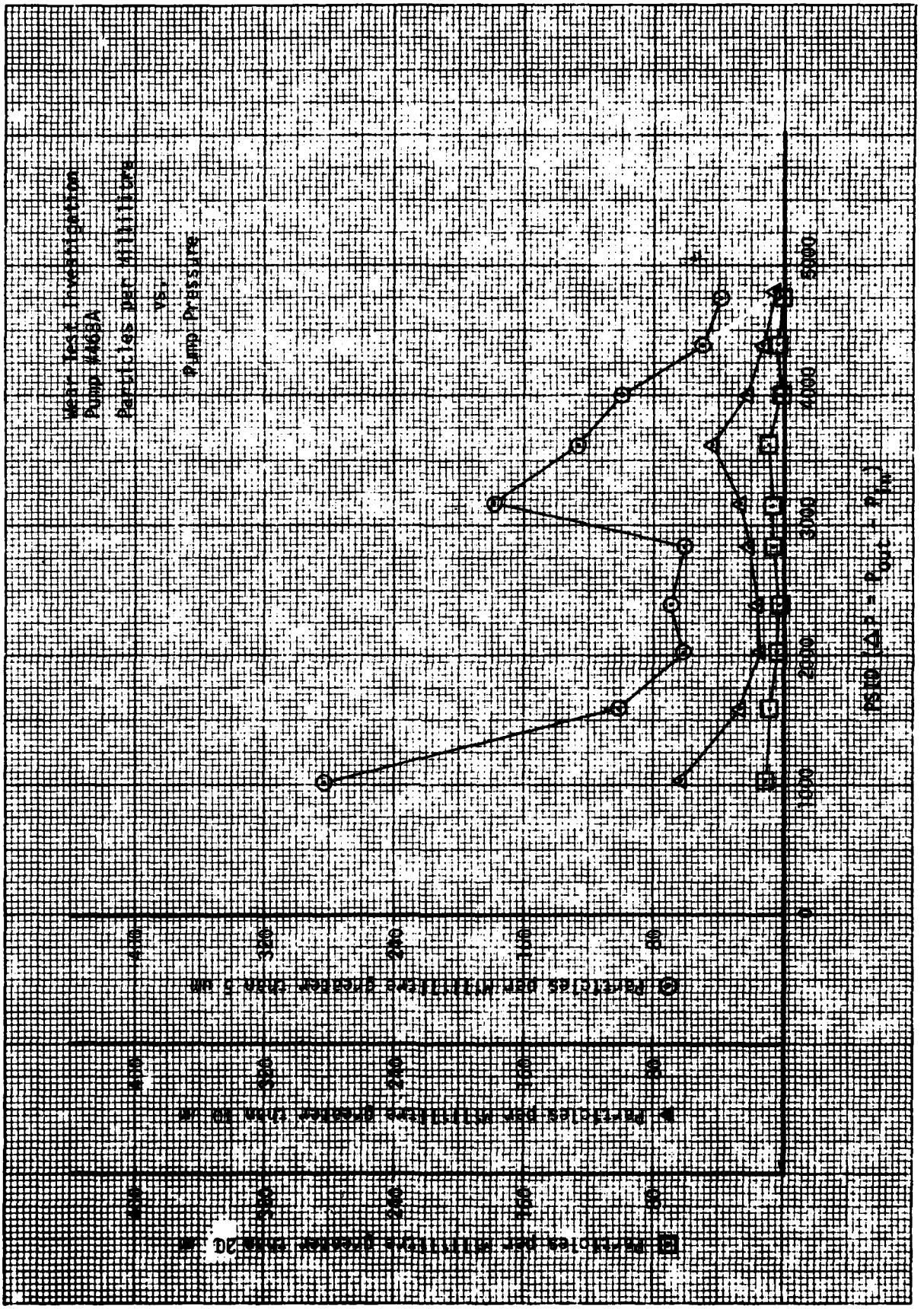
ΔT T out - T in (°F)	ΔP P out - P in (PSI)	Q Pump (Flow in GPM)	Vol. Eff. E_V (%)	Time Into Test (Hours)	(ΔP) Filter Patch (psid)	(Q) Filter Patch (ml/min)	Particles per millilitre greater than:					
							5 um		10 um		20 um	
							IN	OUT	IN	OUT	IN	OUT
3.6	1209	29.1	95	0.5	69	588	362	612	62	109	13	13
3.4	1213	29.2	96	1.4	17	234	176	105	31	34	6	7
3.2	1194	28.9	95	2.4	25	222	140	138	20	46	6	14
4.7	1590	28.2	92	3.0	15	402	99	134	19	32	4	10
4.7	1594	28.2	92	3.7	12	438	302	68	71	23	11	6
6.4	2018	27.5	90	4.4	11	582	161	99	27	19	5	6
2.3	2025	27.5	90	5.4	10	498	76	45	15	12	2	2
6.5	2016	27.6	91	6.1	9	540	80	40	12	14	3	6
8.0	2430	26.9	88	6.9	9	780	43	39	13	8	6	2
7.1	2312	27.4	90	7.9	9	600	88	101	17	24	5	8
7.8	2400	27.5	90	8.4	14	660	40	69	7	17	3	3
9.6	2849	26.6	94	9.3	12	840	44	61	13	21	4	6

WEAR TEST INVESTIGATION DATA FOR PUMP #468 A

ΔT T out - T in (°F)	ΔP P out - P in (PSI)	Q Pump (Flow in GPM)	Vol. Eff. E_V (%)	Time Into Test (Hours)	(ΔP) Filter Patch (psid)	(Q) Filter Patch (ml/min)	Particles per millilitre greater than: 5 um IN	5 um OUT	10 um IN	10 um OUT	20 um IN	20 um OUT
11.2	3162	25.9	85	10.3	22	1092	59	402	30	22	4	4
11.3	3199	26.0	85	11.3	24	942	99	72	26	16	8	3
11.4	3157	25.2	82	12.3	84	1130	84	132	22	33	4	7
11.1	3170	25.5	84	13.3	30	960	110	111	20	37	6	11
13.3	3584	24.4	80	14.3	47	1260	138	64	29	16	7	4
13.0	3608	24.8	81	15.1	43	1200	63	269	14	95	3	17
13.0	3618	25.0	82	16.0	48	1160	117	56	26	21	8	7
14.0	4009	25.3	83	17.0	46	1310	106	147	13	20	3	5
14.9	3993	24.8	81	17.4	41	1280	43	46	14	12	3	3
14.4	3998	25.0	82	17.9	43	1310	40	104	10	36	11	2
20.0	4392	22.6	74	18.3	42	1710	116	49	32	12	5	4
19.2	4397	22.7	74	18.8	25	1550	143	48	31	11	5	2

WEAR TEST INVESTIGATION DATA FOR PUMP #468 A

ΔT T out - T in (°F)	ΔP P out - P in (PSI)	Q Pump (Flow in GPM)	Vol. Eff. E_V (%)	Time Into Test (Hours)	(ΔP) Filter Patch (psid)	(Q) Filter Patch (ml/min)	Particles per millilitre greater than: 5 um IN	5 um OUT	10 um IN	10 um OUT	20 um IN	20 um OUT
19.0	4390	22.8	75	19.2	49	1550	116	55	30	18	7	5
21.3	4768	22.4	73	20.2	131	4128	177	51	33	8	9	2
21.5	4795	22.0	72	21.2	98	3784	172	24	37	4	11	1



22-116 CROSS SECTION 20 SQUARES TO INCH

WEAR TEST INVESTIGATION DATA FOR PUMP #468 B

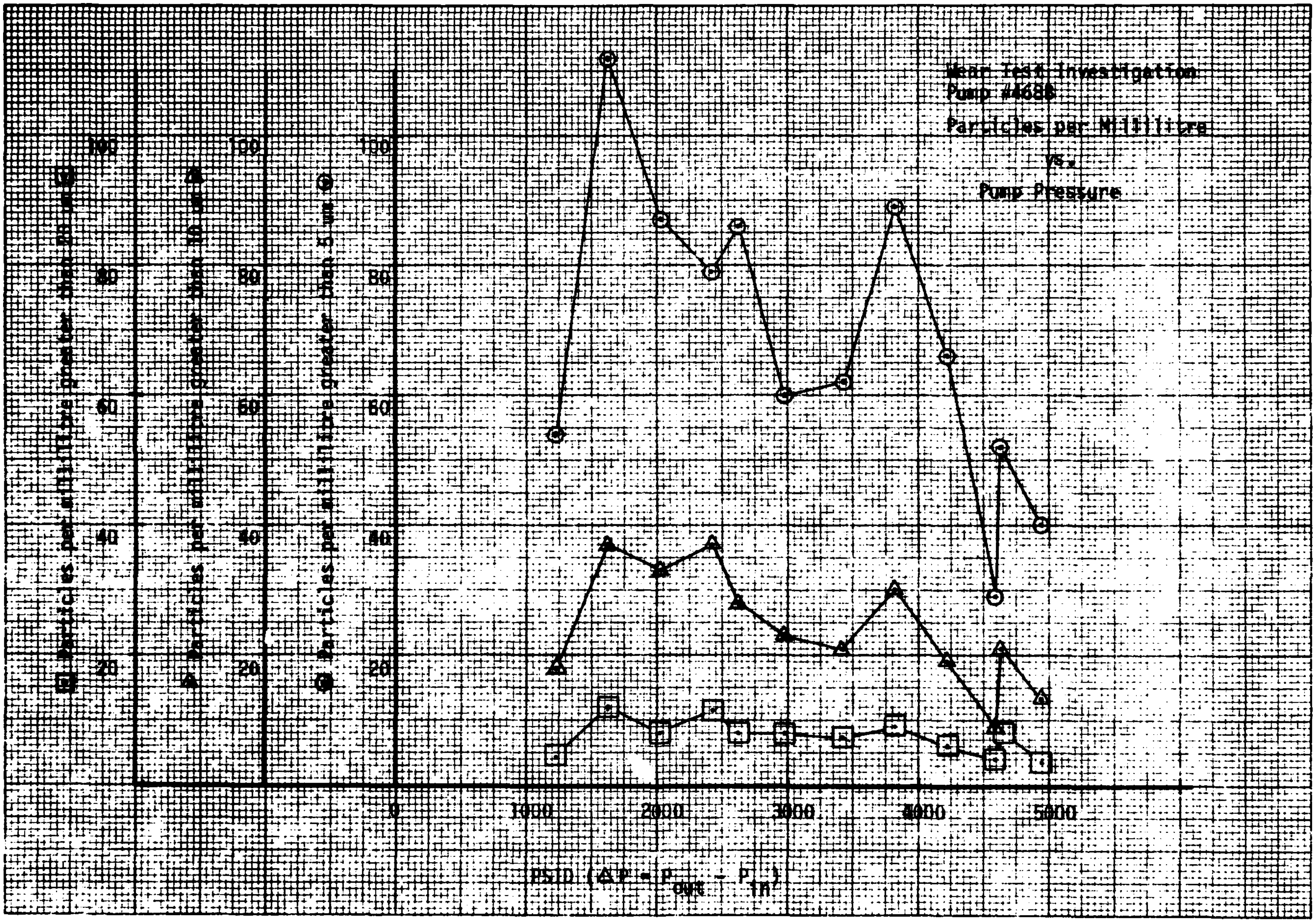
ΔT T out - T in (°F)	ΔP P out - P in (PSI)	Q Pump (Flow in GPM)	Vol. Eff. E_V (%)	Time Into Test (Hours)	(ΔP) Filter Patch (psid)	(Q) Filter Patch (ml/min)	Particles per millilitre greater than:					
							5 um		10 um		20 um	
							IN	OUT	IN	OUT	IN	OUT
4.0	1243	27.8	92	0.3	50	2248	60	30	18	9	4	3
3.8	1252	27.8	92	0.7	73	1992	77	28	25	9	8	2
3.6	1226	29.0	96	1.7	6	190	37	106	10	37	3	8
4.9	1645	27.9	93	2.2	5	290	62	92	17	31	5	10
4.9	1647	27.9	93	2.6	4	330	103	133	36	43	11	14
6.3	2036	27.4	91	3.1	3	440	117	105	41	39	11	9
6.4	2036	27.4	91	3.5	2	450	84	69	33	27	9	7
8.0	2423	27.0	90	4.1	2	575	167	84	71	43	24	15
8.1	2426	27.0	90	4.7	1	560	88	75	29	31	10	8
8.9	2631	26.7	89	5.7	2	555	48	106	10	37	2	10
8.8	2633	26.5	88	6.2	7	610	69	67	16	19	4	6
10.4	3000	25.9	86	6.7	1	750	127	60	48	21	13	6

WEAR TEST INVESTIGATION DATA FOR PUMP #468B

ΔT T out - T in (°F)	ΔP P out - P in (PSI)	Q Pump (Flow in GPM)	Vol. Eff. E_V (%)	Time Into Test (Hours)	(ΔP) Filter Patch (psid)	(Q) Filter Patch (ml/min)	Particles per millilitre greater than:					
							5 um		10 um		20 um	
							IN	OUT	IN	OUT	IN	OUT
10.5	2987	25.7	85	7.1	14	770	116	60	28	26	9	10
13.0	3422	24.7	82	7.5	5	1010	84	75	26	28	7	10
12.3	3493	25.5	85	7.8	33	940	88	52	28	19	6	7
11.6	3352	25.8	86	8.8	23	730	146	59	26	16	6	6
14.1	3825	25.1	84	9.2	5	1005	119	95	33	26	8	9
14.0	3831	25.1	83	9.5	5	1005	88	83	26	34	11	9
16.2	4214	24.6	82	9.8	1	1190	91	68	27	19	9	6
15.9	4210	24.7	82	10.4	1	1140	87	64	29	20	8	7
18.4	4605	23.9	79	10.8	2	1390	71	31	19	11	6	6
18.7	4593	23.7	79	11.3	1	1330	87	27	19	8	6	2
18.3	4624	24.1	80	12.3	4	1185	82	23	20	5	5	2
18.2	4621	24.1	80	12.9	4	1210	115	81	27	37	6	17

WEAR TEST INVESTIGATION DATA FOR PUMP #468B

ΔT T out - T in (°F)	ΔP P out - P in (PSI)	Q Pump (Flow in GPM)	Vol. Eff. E_V (%)	Time Into Test (Hours)	(ΔP) Filter Patch (psid)	(Q) Filter Patch (ml/min)	Particles per millilitre greater than: 5 um IN	5 um OUT	10 um IN	10 um OUT	20 um IN	20 um OUT
27.9	4968	20.4	68	13.7	5	1365	196	58	42	20	7	3
27.5	4929	20.6	69	14.0	1	1410	126	22	24	7	6	4



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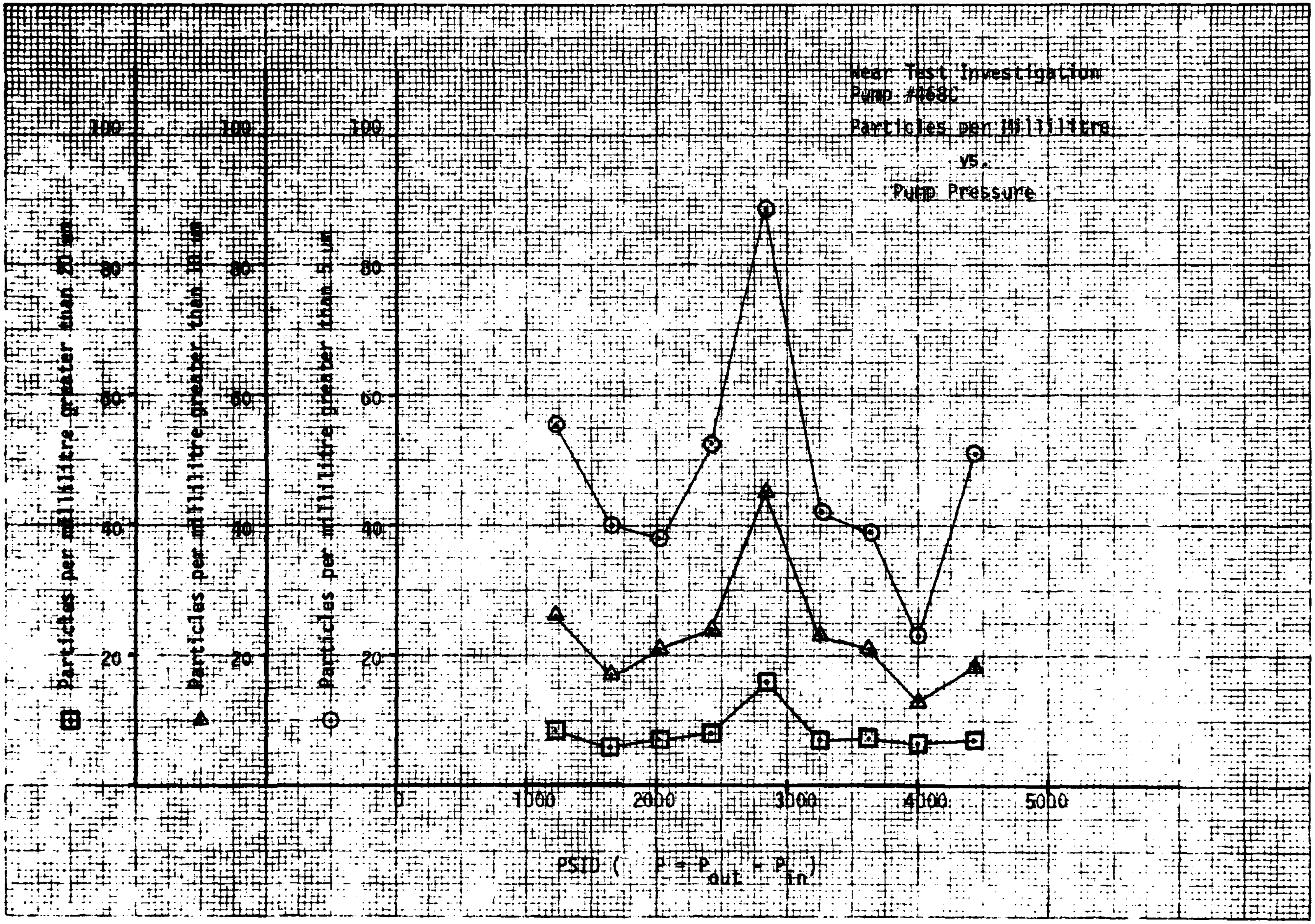
WEAR TEST INVESTIGATION DATA FOR PUMP #468C

ΔT T out - T in (°F)	ΔP P out - P in (PSI)	Q Pump (Flow in GPM)	Vol. Eff. Ev (%)	Time Into Test (Hours)	~~(ΔP) Filter Patch (psid)~~	~~(Q) Filter Patch (ml/min)~~	Particles per millilitre greater than: 5 um IN	5 um OUT	10 um IN	10 um OUT	20 um IN	20 um OUT
3.4	1230	29.3	96	0.4			42	73	20	36	8	10
3.2	1226	29.2	95	1.1			37	38	16	16	6	7
4.8	1655	28.4	93	2.0			43	40	21	17	10	6
		Data Point In Error					75	25	31	11	11	6
6.2	2029	28.1	92	2.8			49	44	21	27	9	9
6.2	2012	28.0	91	3.4			37	32	21	16	8	5
7.8	2424	27.5	90	4.0			27	37	13	20	3	8
7.7	2416	27.5	90	4.7			42	68	20	28	8	8
9.5	2851	26.8	87	5.8			32	132	12	67	5	23
9.5	2832	26.6	87	6.4			25	45	11	23	4	8
11.2	3245	26.0	85	7.0			46	33	23	18	10	5
11.3	3244	25.9	85	7.7			36	51	15	28	5	9

WEAR TEST INVESTIGATION DATA FOR PUMP #468C

ΔT T out - T in (°F)	ΔP P out - P in (PSI)	Q Pump (Flow in GPM)	Vol. Eff. E_V (%)	Time Into Test (Hours)	~~(ΔP) Filter Patch (psid)~~	~~(Q) Filter Patch (ml/min)~~	Particles per millilitre greater than: 5 um IN	5 um OUT	10 um IN	10 um OUT	20 um IN	20 um OUT
13.2	3627	25.5	83	8.3			35	52	13	29	5	10
13.3	3627	25.5	83	8.7			82	26	33	13	14	5
13.3	4025	27.2	89	9.7			53	31	27	16	9	8
15.3	3973	25.3	83	10.5			44	15	19	10	7	5
17.8	4443	24.8	81	11.0			71	41	20	17	8	6
17.7	4430	24.6	80	11.4			124	61	55	20	18	8



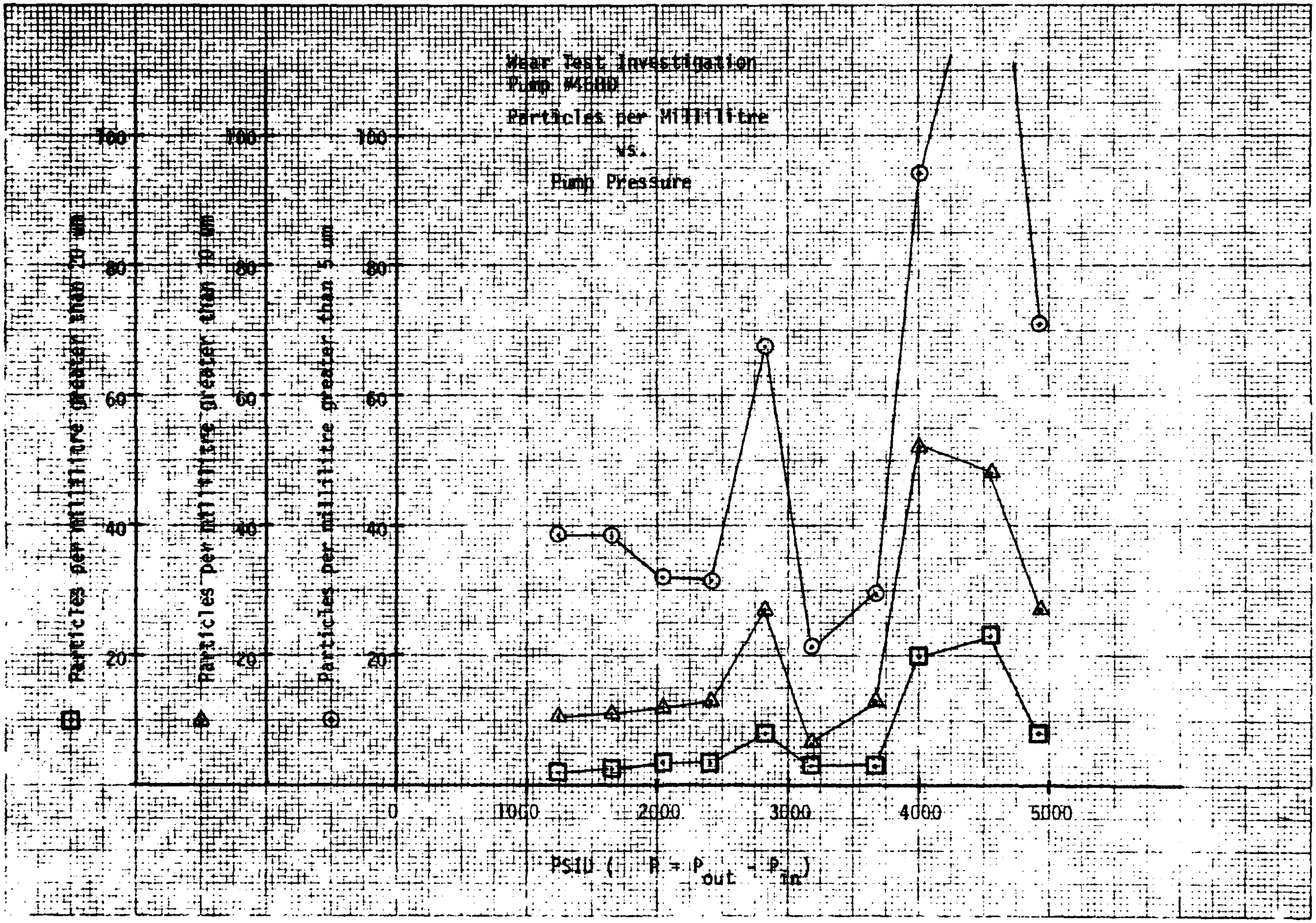
22-116 CROSS SECTION

WEAR TEST INVESTIGATION DATA FOR PUMP #468D

ΔT T out - T in (°F)	ΔP P out - P in (PSI)	Q Pump (Flow in GPM)	Vol. Eff. Ev (%)	Time Into Test (Hours)	(ΔP) Filter Patch (psid)	(Q) Filter Patch (ml/min)	Particles per millilitre greater than: 5 um IN	5 um OUT	10 um IN	10 um OUT	20 um IN	20 um OUT
3.8	1241	29.0	93	0.4			87	46	28	9	8	2
3.9	1248	28.9	93	1.0			63	31	12	12	4	2
5.4	1656	28.2	91	1.6			33	25	12	11	4	3
5.4	1656	28.1	90	2.1			78	52	18	11	5	2
6.8	2046	27.5	89	2.6			36	46	8	16	2	4
7.0	2039	27.6	89	3.0			45	18	10	8	2	3
8.3	2413	27.3	88	4.0			58	29	24	13	4	5
8.3	2410	27.3	88	4.0			133	34	47	13	23	2
10.0	2837	26.7	86	4.2			47	95	15	39	5	10
10.0	2811	26.4	85	4.7			43	40	10	13	3	6
12.0	3244	25.8	83	5.2			79	25	33	7	10	4
12.0	3130	25.8	83	5.6			23	18	9	6	4	2

WEAR TEST INVESTIGATION DATA FOR PUMP #468D

ΔT T out - T in (°F)	ΔP P out - P in (PSI)	Q Pump (Flow in GPM)	Vol. Eff. E_V (%)	Time Into Test (Hours)	(ΔP) Filter Patch (psid)	(Q) Filter Patch (ml/min)	Particles per millilitre greater than: 5 um IN	5 um OUT	10 um IN	10 um OUT	20 um IN	20 um OUT
14.3	3673	25.4	82	5.9			29	29	13	13	5	3
14.0	3665	25.3	81	6.3			39	30	10	13	3	3
13.2	3998	27.2	88	7.3			97	94	50	52	20	20
16.1	3887	24.7	79	7.5			141	133	66	68	26	23
16.1	3895	24.7	80	8.1			62	123	25	59	10	22
18.8	4545	24.2	78	8.6			51	137	28	68	12	23
19.0	3566	24.1	78	8.9			145	128	40	51	16	17
22.1	4927	23.5	76	9.3			146	71	54	27	22	8
23.8	4659	22.2	72	9.4								



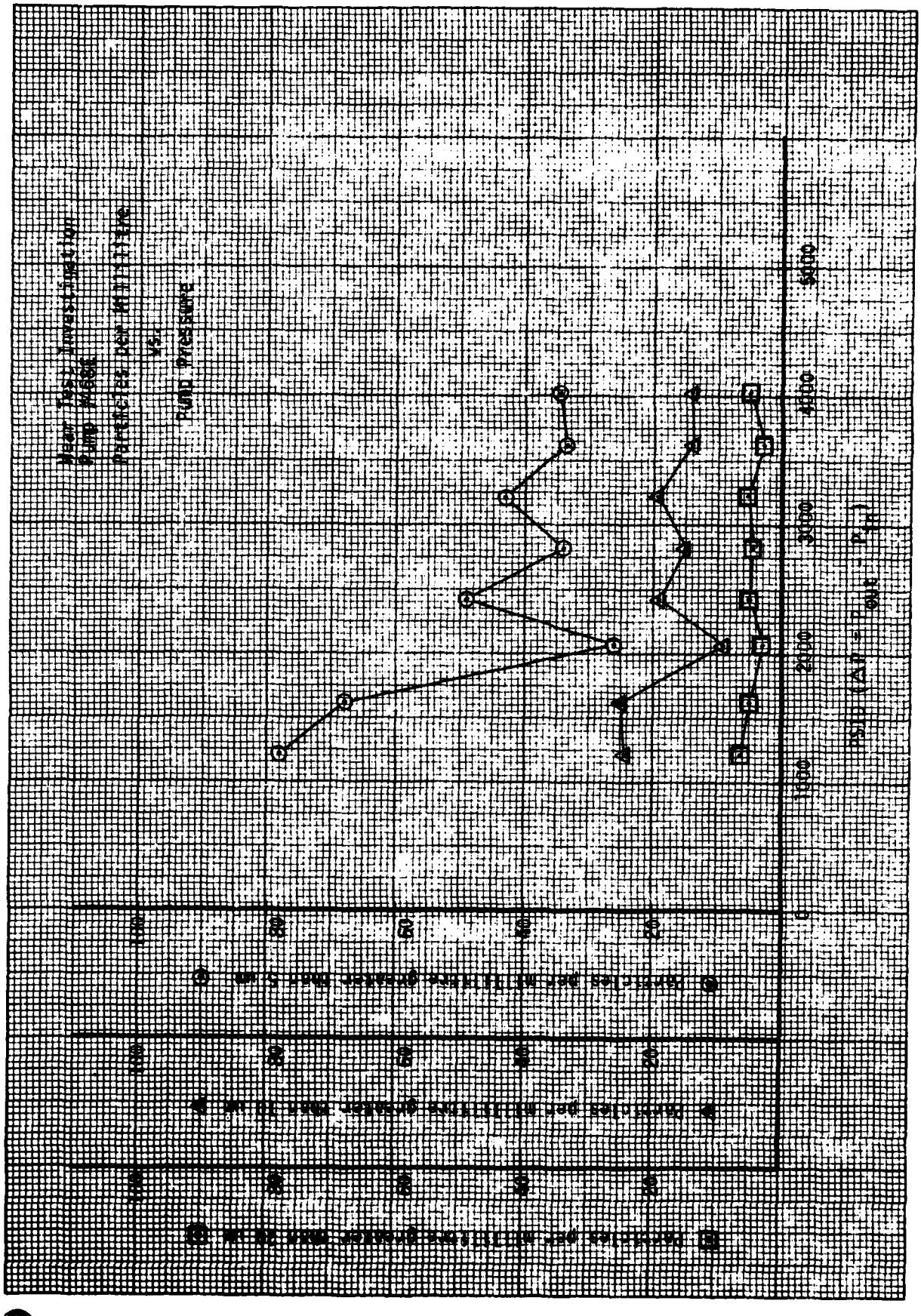
22-116 CROSS SECTION

WEAR TEST INVESTIGATION DATA FOR PUMP #468E

ΔT T out - T in (°F)	ΔP P out - P in (PSI)	Q Pump (Flow in GPM)	Vol. Eff. E_V (%)	Time Into Test (Hours)	(ΔP) Filter Patch (psid)	(Q) Filter Patch (ml/min)	Particles per millilitre greater than: 5 um IN	5 um OUT	10 um IN	10 um OUT	20 um IN	20 um OUT
3.8	1245	28.8	94	0.3			119	67	32	26	8	6
3.6	1225	28.8	94	1.3			122	100	36	28	7	9
3.8	1217	28.8	94	1.4			135	57	50	19	16	4
5.0	1627	28.5	93	2.4			62	126	16	46	5	10
4.8	1607	28.6	93	2.8			88	42	25	13	5	2
5.1	1612	28.5	93	3.2			61	37	18	16	6	3
6.9	2065	27.7	90	3.8			69	18	24	7	9	2
6.7	2064	27.5	90	4.2			66	34	16	11	5	4
8.4	2436	27.0	88	4.5			143	63	50	21	12	6
8.2	2436	27.0	88	5.2			63	35	18	17	3	4
9.9	2825	26.4	86	5.6			87	36	21	15	5	4
10.1	2804	26.1	85	6.0			63	32	18	15	5	5

WEAR TEST INVESTIGATION DATA FOR PUMP #468 E

ΔT T out - T in (°F)	ΔP P out - P in (PSI)	Q Pump (Flow in GPM)	Vol. Eff. E_V (%)	Time Into Test (Hours)	(ΔP) Filter Patch (psid)	(Q) Filter Patch (m)/min)	Particles per millilitre greater than: 5 um IN	5 um OUT	10 um IN	10 um OUT	20 um IN	20 um OUT
12.2	3222	25.6	84	6.5			107	17	34	5	8	1
11.8	3221	25.8	84	7.5			72	103	19	49	3	13
12.3	3189	25.1	82	7.9			56	9	19	4	2	2
14.6	3625	24.5	80	8.3			80	41	29	17	7	4
15.1	3607	24.1	79	8.6			125	26	28	11	7	3
16.2	4028	24.6	80	9.0			41	30	13	12	4	5
16.3	4019	24.5	80	9.3			23	39	8	16	3	6
15.5	4444	27.2	89	10.3								



22-116 · CROSS SECTION 20 SQUARES TO INCH -23-

WEAR TEST INVESTIGATION DATA FOR PUMP #468 F

ΔT T out - T in (°F)	ΔP P out - P in (PSI)	Q Pump (Flow in GPM)	Vol. Eff. E_V (%)	Time Into Test (Hours)	(ΔP) Filter Patch (psid)	(Q) Filter Patch (ml/min)	Particles per millilitre greater than: 5 um IN	5 um OUT	10 um IN	10 um OUT	20 um IN	20 um OUT
4.4	1388	29.616	95.7	0.0	1.8	120	143	327	37	101	6	37
4.6	1396	29.491	95.3	1.0	3.4	100	103	237	33	57	5	12
4.5	1393	29.244	94.5	2.5	25.8	106	34	283	13	65	2	10
5.2	1592	28.972	93.7	4.75	4.6	80	50	26,559	18	6544	3	1028
4.9	1587	28.696	92.7	5.5	5.0	80	61	1238	15	327	3	59
5.4	1588	28.490	92.1	6.5	3.92	90	22	1070	11	287	4	53
5.2	1584	28.435	91.9	7.5	3.86	90	32	883	11	218	5	36
5.2	1586	28.457	92.0	8.25	4.0	90	89	1155	31	283	4	49
5.9	1800	27.949	90.4	9.0	4.6	120	40	506	11	155	2	36
5.9	1798	27.912	90.2	10.0	4.24	120	59	726	27	192	7	36
5.8	1799	27.986	90.5	10.75	3.5	120	44	2420	17	614	4	93
6.8	2000	27.706	89.6	11.5	3.18	140	30	576	10	176	2	36

WEAR TEST INVESTIGATION DATA FOR PUMP #468 F

ΔT T out - T in (°F)	ΔP P out - P in (PSI)	Q Pump (Flow in GPM)	Vol. Eff. E_V (%)	Time Into Test (Hours)	(ΔP) Filter Patch (psid)	(Q) Filter Patch (ml/min)	Particles per millilitre greater than: 5 um IN	5 um OUT	10 um IN	10 um OUT	20 um IN	20 um OUT
7.5	2000	27.581	89.2	12.5	3.0	140	42	860	20	252	6	42
5.7	1997	29.359	94.9	13.5	7.0	104	417	531	87	139	16	32
6.1	1990	29.193	94.4	14.5	9.0	100	228	448	60	134	9	34
6.5	2188	28.792	93.1	15.25	6.0	120	170	369	45	114	6	29
6.6	2176	28.928	93.5	15.75	8.0	118	255	275	68	72	10	15
7.1	2376	28.604	92.5	16.5	8.0	118	94	141	22	37	3	7
7.3	2374	28.670	92.7	18.0	3.0	140	132	202	30	64	6	16
7.8	2594	28.468	92.0	20.25	2.1	100	138	383	30	110	5	23
8.1	2593	28.420	91.9	20.75	3.5	116	86	277	20	90	4	15
8.1	2597	28.221	91.2	21.25	2.6	128	89	131	17	36	2	8
9.0	2799	28.255	91.4	21.75	3.1	124	128	80	33	26	8	4
8.9	2800	28.299	91.5	22.25	2.7	126	140	99	37	31	7	7

WEAR TEST INVESTIGATION DATA FOR PUMP #468 F

ΔT T out - T in (°F)	ΔP P out - P in (PSI)	Q Pump (Flow in GPM)	Vol. Eff. E_V (%)	Time Into Test (Hours)	(ΔP) Filter Patch (psid)	(Q) Filter Patch (ml/min)	Particles per millilitre greater than: 5 um IN	5 um OUT	10 um IN	10 um OUT	20 um IN	20 um OUT
9.6	3010	27.960	90.4	23.25	3.1	120	78	172	20	51	2	9
9.7	3009	27.890	90.2	24.00	3.5	120	138	80	45	32	8	9
9.7	3013	28.012	90.6	24.5	2.4	148	137	129	58	40	13	8
9.6	3010	27.953	90.4	25.25	2.5	145	52	47	10	18	1	4
9.7	3022	28.240	91.3	25.75	5.0	124	89	2601	19	874	4	309
9.7	3016	28.317	91.5	26.25	2.0	74	59	587	13	129	1	23
				CAPILLARY TUBING INSTALLED								
9.4	3000	28.015	90.6	27.0	11.4	560	156	791	23	35	5	5
9.7	3003	27.846	90.0	27.25	29	748	106	82	19	27	4	11
9.5	3009	28.045	90.7	27.75	20	800	91	97	19	28	4	8
9.9	3185	27.187	87.9	28.25	14	424	93	104	21	32	3	9
10.3	3189	27.140	87.7	29.0	20	910	176	59	44	21	11	6

WEAR TEST INVESTIGATION DATA FOR PUMP #468 F

ΔT T out - T in (°F)	ΔP P out - P in (PSI)	Q Pump (Flow in GPM)	Vol. Eff. E_V (%)	Time Into Test (Hours)	(ΔP) Filter Patch (psid)	(Q) Filter Patch (ml/min)	Particles per millilitre greater than: 5 um IN	5 um OUT	10 um IN	10 um OUT	20 um IN	20 um OUT
11.4	3386	27.250	88.1	29.5	25		102	53	25	13	5	3
10.9	3368	27.614	89.3	30.0	20	840	85	50	20	9	5	2
11.8	3567	27.099	87.6	30.5	23	1040	77	221	12	74	2	23
11.8	3635	27.368	88.5	31.0	12.3	800	162	264	50	92	11	34
12.1	3646	27.165	87.8	31.5	10.0	880	269	48	78	13	12	3
12.7	3814	27.018	87.4	31.75	13.6	880	91	222	21	75	3	16
12.5	3811	26.992	87.3	32.25	9.0	840	133	353	31	109	5	32
12.6	3816	27.051	87.5	32.75	11.2	880	102	149	19	41	5	8
13.9	3988	26.573	85.9	33.75	13.0	1340	208	122	46	40	4	10
13.6	3992	26.933	87.1	34.0	27	1260	299	163	81	52	20	12
13.7	3995	26.956	87.2	34.5	24	1220	111	132	34	36	9	6
13.8	3996	27.007	87.3	35.0	11.6	1260	90	171	37	53	6	15

WEAR TEST INVESTIGATION DATA FOR PUMP #468 F

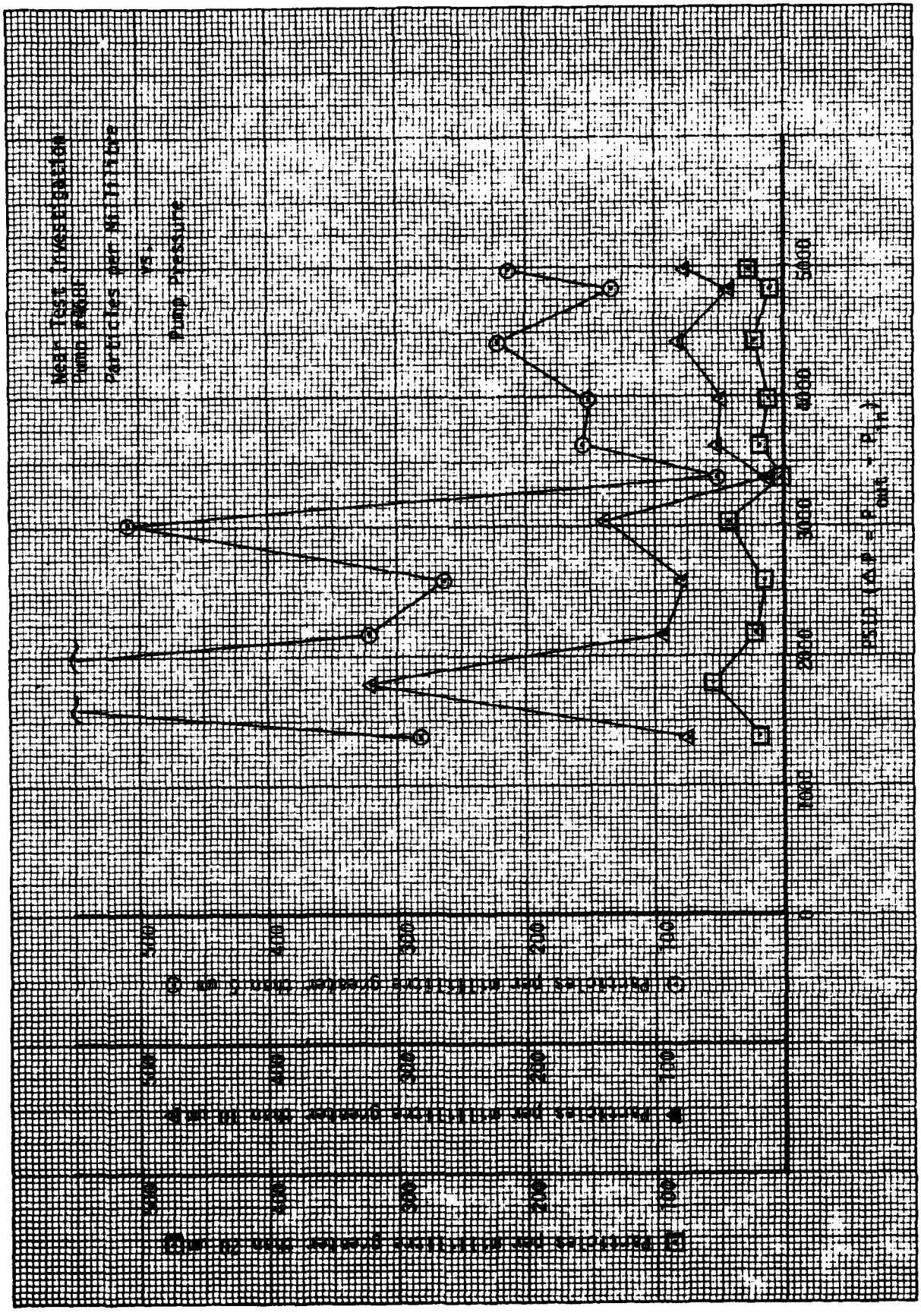
ΔT T out - T in (°F)	ΔP P out - P in (PSI)	Q Pump (Flow in GPM)	Vol. Eff. E_V (%)	Time Into Test (Hours)	(ΔP) Filter Patch (psid)	(Q) Filter Patch (ml/min)	Particles per millilitre greater than: 5 um IN	5 um OUT	10 um IN	10 um OUT	20 um IN	20 um OUT
13.6	3998	26.981	87.2	35.5	11.8	1260	54	173	13	64	4	14
14.7	4201	26.584	85.9	35.75	21.0	1480	46	92	11	29	3	6
14.8	4207	26.529	85.8	36.5	20.6	1560	88	291	20	107	5	34
14.7	4209	26.558	85.9	37.0	13.5	1420	59	390	15	144	4	37
14.5	4205	26.488	85.6	37.25	25.0	1340	365	158	115	57	40	15
15.9	4424	26.208	84.7	38.0	19.0	1360	109	349	31	135	10	39
15.9	4423	26.054	84.2	38.25	18.2	1400	102	169	37	61	14	18
15.9	4427	26.139	84.5	38.75	13.0	1500	115	150	56	51	18	12
16.8	4591	25.966	83.9	39.0	17.2	1560	120	175	56	72	20	26
16.7	4596	25.944	83.9	39.5	20.0	1540	128	187	35	79	8	23
16.7	4594	25.910	83.8	39.75	21.0	1440	86	285	18	94	3	27
16.8	4598	25.896	83.7	40.25	18.2	1560	45	138	11	42	4	11

WEAR TEST INVESTIGATION DATA FOR PUMP #468 F

ΔT T out - T in (°F)	ΔP P out - P in (PSI)	Q Pump (Flow in GPM)	Vol. Eff. E_V (%)	Time Into Test (Hours)	(ΔP) Filter Patch (psid)	(Q) Filter Patch (ml/min)	Particles per millilitre greater than: 5 um IN	5 um OUT	10 um IN	10 um OUT	20 um IN	20 um OUT
17.9	4823	25.550	82.6	40.5	18.5	1600	189	113	87	31	19	9
18.0	4827	25.513	82.5	41.0	33.7	1680	46	227	10	76	2	20
17.9	4825	25.579	82.7	41.25	30.5	1640	46	72	12	21	3	3
17.8	4829	25.583	82.7	41.75	28.5	1540	66	125	24	44	7	9
19.1	5019	25.300	81.8	45.25	24.7	1660	143	293	26	86	7	21
19.0	5036	25.72	83.2	42.92	21.0	1880	457	1247	102	464	22	155
19.0	5030	25.70	83.2	43.17	24.0	1870	127	102	35	38	7	12
19.0	5025	25.67	83.1	43.42	28	1890	383	187	73	73	13	23
18.0	5029	25.67	83.1	43.67	30	1820	279	111	55	33	10	11
18.0	4983	26.1	84.4	44.47	17.0	1670	184	214	69	97	24	43
18.2	4974	25.98	84.0	44.62	21.5	1860	135	216	34	81	7	29
18.2	4988	25.89	83.7	44.89	24	1890	125	91	29	28	5	8

WEAR TEST INVESTIGATION DATA FOR PUMP #468F

ΔT T out - T in (°F)	ΔP P out - P in (PSI)	Q Pump (Flow in GPM)	Vol. Eff. E_V (%)	Time Into Test (Hours)	(ΔP) Filter Patch (psid)	(Q) Filter Patch (ml/min)	Particles per millilitre greater than: 5 um IN	5 um OUT	10 um IN	10 um OUT	20 um IN	20 um OUT
18.2	4976	25.79	83.4	45.10	20	1760	58	146	17	51	5	17
18.0	4962	25.98	84.0	45.55	32	1830	73	78	19	30	4	11
18.3	4962	25.98	84.0	45.87	28	1880	78	62	20	20	6	5
17.8	4960	26.05	84.2	46.17	30	1840	110	82	27	23	5	9
18.0	4970	26.16	84.6	46.47	32	1890	61	46	14	13	2	4
18.1	4956	25.86	83.6	46.80	37	1870	199	118	57	39	13	11



WEAR TEST OBSERVATIONS AND CONCLUSIONS

1. Pumps 468A, 468B, and 468C were broken in at 3000 psi while pumps 468D, 468E, and 468F were broken in at 600 psi.

2. The pumps broken in at 3000 psi experienced a greater change in overall efficiency than the ones broken at 600 psi.

3. The pumps broken in at 3000 psi had a larger change in volumetric efficiency than the pumps broken in at 600 psi.

4. There was a minor change in the mechanical efficiency for all of the six pumps with the exception of pump 468B which had an increase of 0.9%.

5. In the wear test, pump 468F had erroneous data up to 3000 psi due to the method used to extract the samples out of the high pressure line. Therefore, the only valid data would be from 3000 to 5000 psid. The data up to 3000 psid was discarded when analyzing the data from the wear test.

6. The graphs of Particles per Milliliter versus Pump Pressure for pumps 468B, 468C, 468D, and 468E show that these pumps shed a smaller amount of particles from 1000 to 3000 psi than pump 468A.

7. Pump 468A shed a larger number of 5 micron particles between 1000 and 2000 psi than at 3000 psi. The particle counts at 10 and 20 microns were very low for this pump. At pressures from 3500 to 4900 psi, the particle counts at 5, 10, and 20 microns were less than 80 particles per milliliter. The overall efficiency of this pump increased 2.1% over the four hour break in period.

8. The 5 micron particles shed by pump 468B ranged from 30 to 120 particles per milliliter. The larger particles (10 and 20 microns) were low in number. The counts ranged from 10 to 38 particles per milliliter at 10 microns and from 3 to 12 particles per milliliter at 20 microns. The overall efficiency of this pump decreased 3.6% over the four hour break in period.

9. The particles shed by pump 468C throughout the wear test were very low in number ranging from 6 to 88 particles per milliliter at all three micron sizes. The overall efficiency of this pump decreased by 1.1% over the four hour break in period.

10. The number of 5 micron particles shed by pump 468D drastically increased at 4000 psi. The number of particles steadily decreased between 4000 and 5000 psi dropping to 70 particles per milliliter at 5 microns. The 10 micron particles ranged from 10 to 52 particles per milliliter and the 20 micron particles ranged from 2 to 23 particles per milliliter. The overall efficiency of this pump decreased only 0.4% over the four hour break in period.

11. The particles shed by pump 468E were low over all three micron sizes (5 um, 10 um, and 20 um) throughout the test. The overall efficiency only decreased .4% over the 4 hour break-in period. This pump only ran up to 4,000 psid due to test stand malfunctioning and causing test pump to blow its shaft seal.

12. Only one of the six test pumps experienced a catastrophic failure (cracked cam ring) this was test pump 468F. Pump 468F also had erroneous data up to 3000 psid, also the pump ran up to 5,000 psid. The only time the data might have indicated a cam ring fatigue was around 3000 psid, but this would be hard to predict because the cam ring fatigue didn't affect the performance of the test pump.

13. As can be seen in the particles per millilitre vs. pump pressure graphs the contamination level was not a linear function nor did it become an exponential function at the contamination levels observed in this wear test (5 um, 10 um, and 20 um particle sizes per millilitre).

14. The limitations of the particle counter sensor (the smallest size particles that it could detect was 5 um) halted our correlation with ferragraphic analysis because most of the wear material appeared to be less than 5 um in size. This same reason might be why the contamination level measured by particle counting, was not a linear function of pressure. Since all pumps showed considerable wear at the end of the test, and no significant, repeatable particle counts were taken during the test, particle counters (limited to 5 um and larger (do not appear to be a viable measuring tool for dynamic wear observations.

15. X-Ray Emission Analysis was terminated during the wear test program, due to problems in correlation with particle counting and not being able to determine the quantity (PPM) of wear metals in the x-rayed oil samples for the various elements which were analyzed. These results indicate that x-ray analysis is not a viable approach for dynamic wear observations. (refer to Appendix H)

16. On line gravimetric analysis (patch pressure drop) was discontinued during test because the flow rate through the patch could not be accurately controlled.

17. The off-line gravimetric analysis that was performed on a selected number of outlet samples revealed correlating data results with the ferrographic analysis.

18. Weighing of the pump cartridge before and after pump testing should be performed in order to determine the loss in mass of the pump cartridge.

WEAR TEST RECOMMENDATIONS:

1. More pumps need to be tested in the 3 hour break-in test at 600 psi and at 3000 psi to verify if any great differences will be made in the wear test data.

2. If particle counting will continue to be one of the wear particle analysis methods, then investigation should be done to come up with an on line counter which would count from 5 um to 1 um or smaller particle sizes.

3. It is recommended that more testing be conducted to correlate dynamic wear with gravimetric filter patching and with ferrographic analysis.

APPENDIX A

VANE PUMP BREAK-IN PROCEDURE

BREAK-IN PROCEDURE FOR FIXED DISPLACEMENT VANE PUMPS:

468A, 468B, 468C

1. Install the test pump in the Break-in and Performance test circuit.

2. Bring system temperature up to 120°F and verify system contamination level to be less than 100 particles per millilitre greater than ten microns.

3. Start the test pump and increase speed to manufacturers rated in less than one minute with the outlet pressure less than 250 psi.

4. Load the pump at the following pressure increments and time intervals. Set speed intitially at manufacturers rated speed and minimum pressure which is less than 250 psi. Do not readjust the speed at each load pressure.

   Minimum pressure for 2 minutes

   25% of continuous rated pressure for 2 minutes

   Minimum pressure for 2 minutes

   50% of continuous rated pressure for 2 minutes

   Minimum pressure for 2 minutes

   75% of continuous rated pressure for 2 minutes

   Minimum pressure for 2 minutes

   100% of continuous rated pressure for 2 minutes

   Minimum pressure for 2 minutes

   At each data point, record inlet and outlet pressures and temperatures, input speed and torque and output flowrate.

5. Run the pump for three hours at maximum rated speed and maximum continuous rated outlet pressure. Record inlet and outlet temperatures and pressures, input speed and torque, and output flowrate every five minutes to determine changes in overall efficiency.

6. At test completion, take an oil sample and verify that the contamination level is less than 100 particles per millilitre greater than 10 microns.

VANE PUMP BREAK-IN PROCEDURE FOR:

468D, 468E, 468F

The remaining three pumps were broken-in using the following procedure. The pumps were run at manufacturer's rated speed with an outlet pressure of 600 psi for three hours using MIL2104C grade 10 oil with 160°F inlet temperature. The following parameters were recorded at five minute intervals; inlet and outlet temperature, inlet and outlet pressure, outlet flowrate, pump speed (rpm) and input torque.

APPENDIX B

Detailed Wear Rate Test Procedure

PUMP WEAR INVESTIGATION

1.0 SCOPE. To provide a method for determining the wear rate and wear transition pressure of a fixed displacement fluid power pump.

2.0 PURPOSE. To determine the wear rate versus operating pressure of a fixed displacement fluid power pump.

3.0 DEFINITION

3.1 Wear Transition Pressure. The operating pressure range at which the pump wear-rate-versus-pressure curve changes from linear to logarithmic.

4.0 PROCEDURE

4.1 Measure and report the initial pump overall efficiency in accordance with NFPA/T3.917R1, except the thermal instability point of the pump shall not be exceeded.

4.2 Test Conditions. Install the pump in the test system and operate under the following conditions.

4.2.1 Test Oil. All tests shall be conducted using oil, lubricating, MIL-L-2104, grade 10 or fluids conforming to SAE J743, except water content shall not exceed 0.05 percent.

4.2.2 Filtration. The control filter shall limit the total number of particles in the test fluid at the pump inlet to no more than 200 particles per milliliter greater than 10 micron.

4.2.3 Wear Additives. The wear additive package of the test oil shall be monitored. In the event the wear additive content of the test oil changes by 20 percent, the wear additives will be brought back to the original level.

4.2.4 Intrumentation and Test Parameter Accuracy. Instrumentation and test parameter accuracy must be maintained within the limits set forth in ANSI B93.27.

4.2.5 Inlet Pressure. The pump inlet oil pressure at the inlet fitting will be maintained at a level that will assure proper filling of the pump and this level shall be maintained within 1 in. Hg of atmospheric pressure throughout the test.

4.2.6 Aeration. The inlet oil must be visually free of entrained air throughout testing.

4.2.7 Speed. Test speeds will be as close to pump manufacturers' rated values as is practical.

4.2.8 Temperature. The pump inlet oil temperature shall be maintained at a level that will assure an oil viscosity that is within the range of the pump manufacturer's minimum viscosity plus 10 SUS.

4.3 Test Procedure.

4.3.1 Break-in the pump either in accordance with the pump manufacturer's recommendations or in accordance with a standard break-in procedure.

4.3.2 Operate the pump for one (1) hour at 1200 psi and determine the wear rate by particle counting, gravimetric wear content, silt rate, or spectagraphic analysis.

4.3.3 Repeat step 4.3.2 with 200 psi incremental increases in pressure until the pump fails.

4.3.4 Repeat steps 4.3.2 and 4.3.3 on each of the remaining five (5) pumps except initiate each pump test at 200 psi higher increments.

4.3.5 Determine the volumetric efficiency at each pressure level except for the final pressure level.

5.0 EVALUATION. After completing the above tests, dissassemble and examine the pumps.

6.0 Prepare a test report with 8 X 10 B/W photos of each tested pump. The report shall include the detailed test procedures, a pressure versus wear rate curve for each pump, a pressure versus efficiency curve for each pump and an analysis of each pump failure.

MODIFICATION TO TEST PROCEDURE

(Reference Paragraph 4.3)

Pump #468F was tested first using the test procedure stated on the previous page with the circuitry in figure A. A few problems were developed while conducting wear test investigations on this pump. First, the time for the contamination level to stabilize was longer than expected. Next, problems occurred with the Fairey Arlon high pressure sample tap in which it was acting like a filter at pressures near 3000 psi and giving bad data. To solve the problem with the Fairey Arlon valve (Model #201) we removed it from the circuit and placed 50 ft. of 1/8" by .030" wall capillary tubing. X-Ray Emission Analysis was performed on the oil samples from Pump #468F but discontinued due to a correlation problem between particle counting and coming up with a quantity count from the X-Ray data. Another factor in discontinuing the X-Ray Analysis was funds set aside in the contract had depleted.

On the remaining pumps the pressure increments were increased to 400 psi, instead of 200 psi; it still required 2 hours of running at each pressure interval starting at 1200 psi and going up to 4800 psi. On line high pressure filter patch test was performed at each of the above pressure intervals for pumps 468F, 468A, 468B, and then discontinued. On line high pressure filter patch test was discontinued because it can be done off line in a more controlled manner.

The remaining pumps were tested using figure B of this section, continuing with Particle Counting and performing gravimetric filter patch analysis on selected samples from each pump. Graphs of Particle Counting VS Pressure were plotted for each test pump.

TEST PUMP SAMPLING CIRCUITRY:

FOR PUMP 468F, 468A, 468B

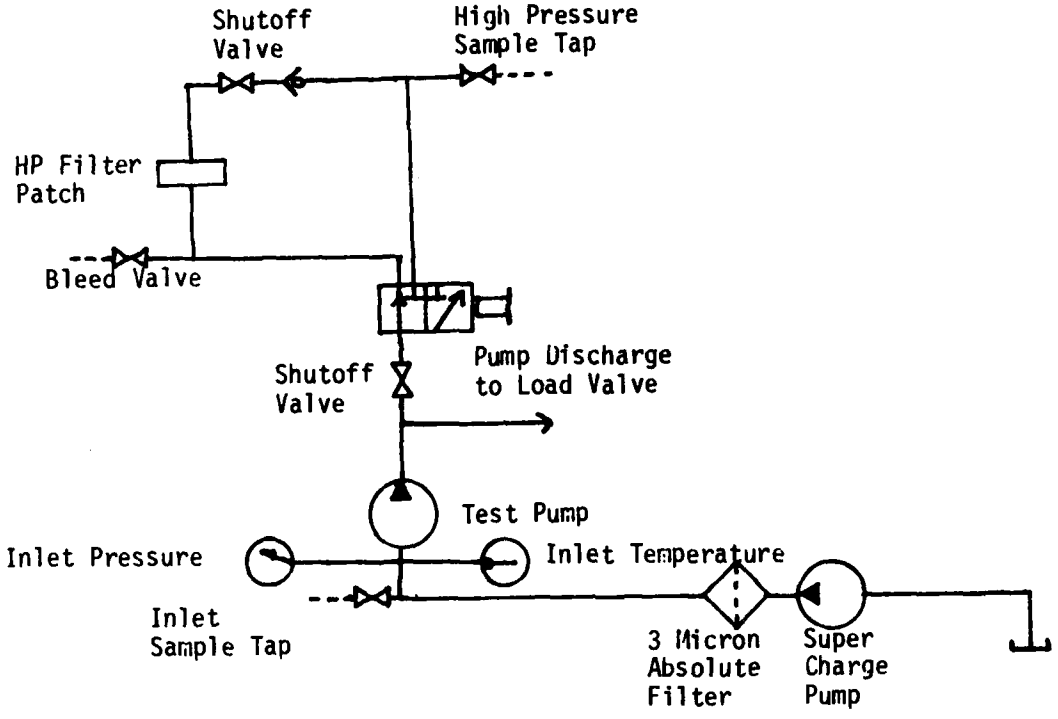


Figure A

TEST PUMP SAMPLING CIRCUITRY:

FOR PUMP 468E, 468D, 468C

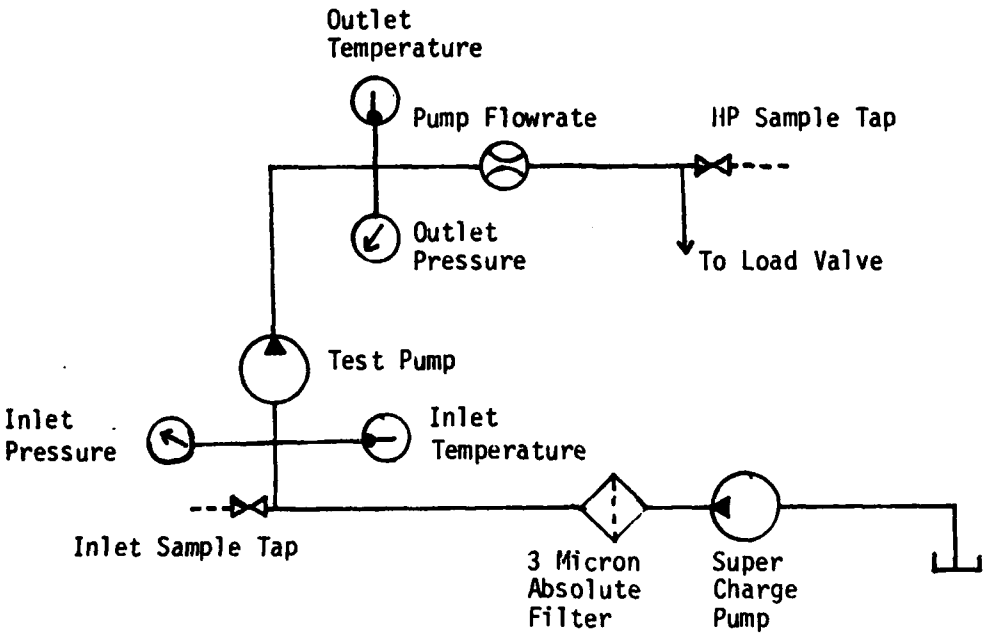


Figure B

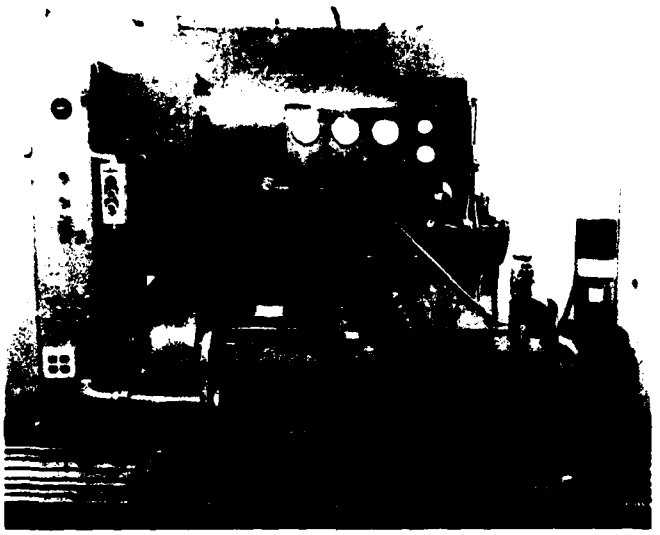
APPENDIX C

TEST FACILITY DESCRIPTION

INSTRUMENTATION SYSTEM AND CIRCUIT SCHEMATICS

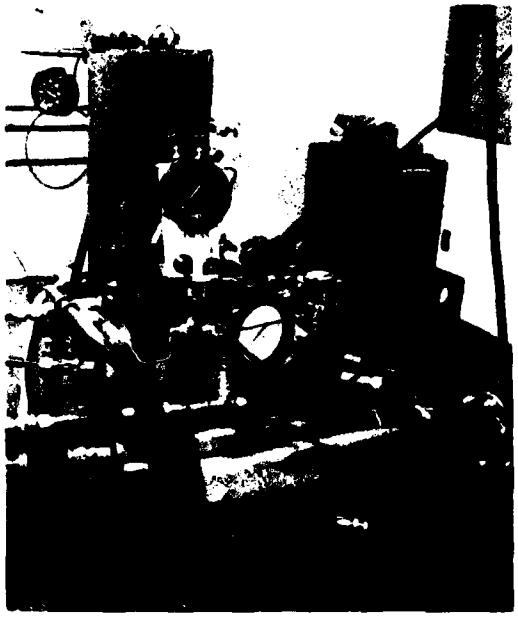
HYDRAULIC POWER SUPPLY

FPI 150 HP Variable Volume Hydraulic Supply



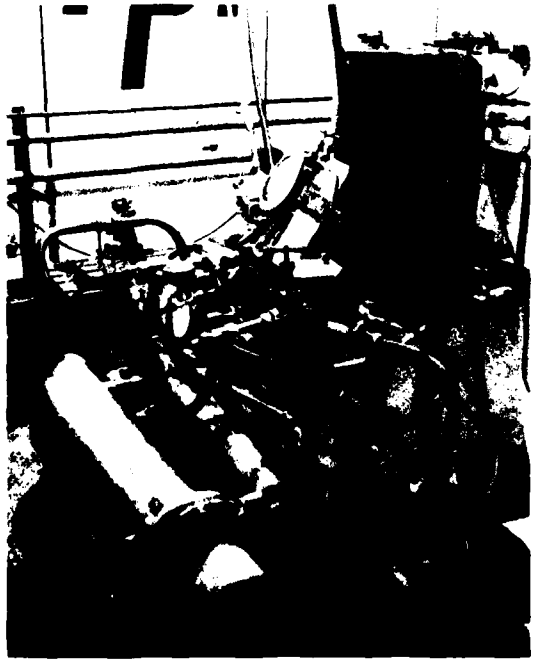
Shown is reservoir, control panel, electric drive motor, variable displacement hydraulic pump and electric servo control on top of pump. This system was used along with a hyraulic motor to drive the test pump.

FLUID CONDITIONING SYSTEM

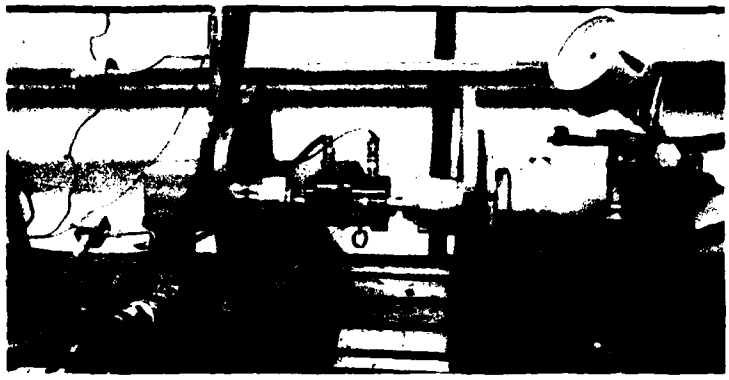


Fluid conditioning system consisting of reservoir with conically shaped bottom, filter strainer, heat exchanger, and electric heater.

Plumbing and various valves used to control the direction of flow in the system. In lower right hand corner is a centrifugal pump used to supercharge the test pump and move fluid throught the conditioning circuit.



TEST CIRCUIT AND COMPONENTS



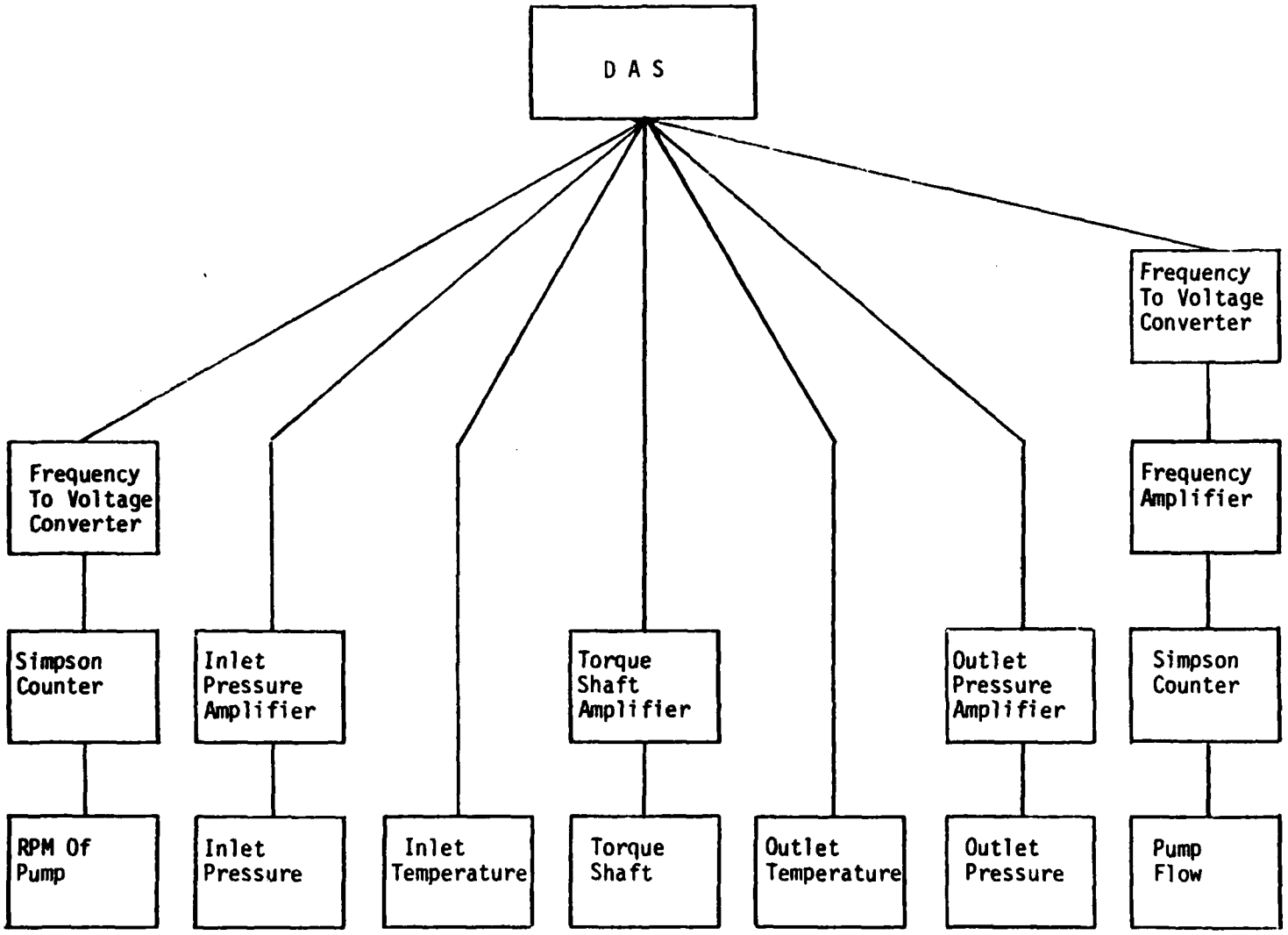
Test bed showing hydraulic drive motor on right, torque shaft in center used to measure input torque, and test pump on left showing various transducers and thermocouples.

In lower left hand corner is solenoid controlled relief valve used to load test pump. The turbine flow meter can be seen in left center of photograph.

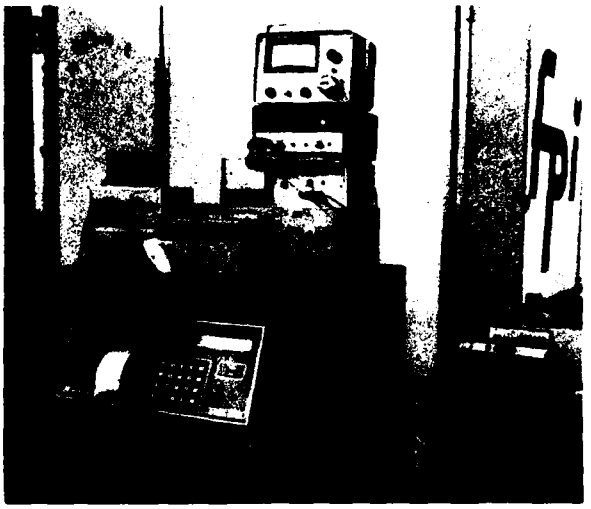
INSTRUMENTATION

The instrumentation, calibration methods and procedures used in this contract, can be referenced to Part 2, of report number 50560, contract DAAK70-77-C-0214, dated November 12, 1979. The traceability statement for measurement of flow, pressure, and temperature are also found in Part 2 of the above mentioned report.

BLOCK DIAGRAM OF INSTRUMENTATION SYSTEM



TEST INSTRUMENTATION

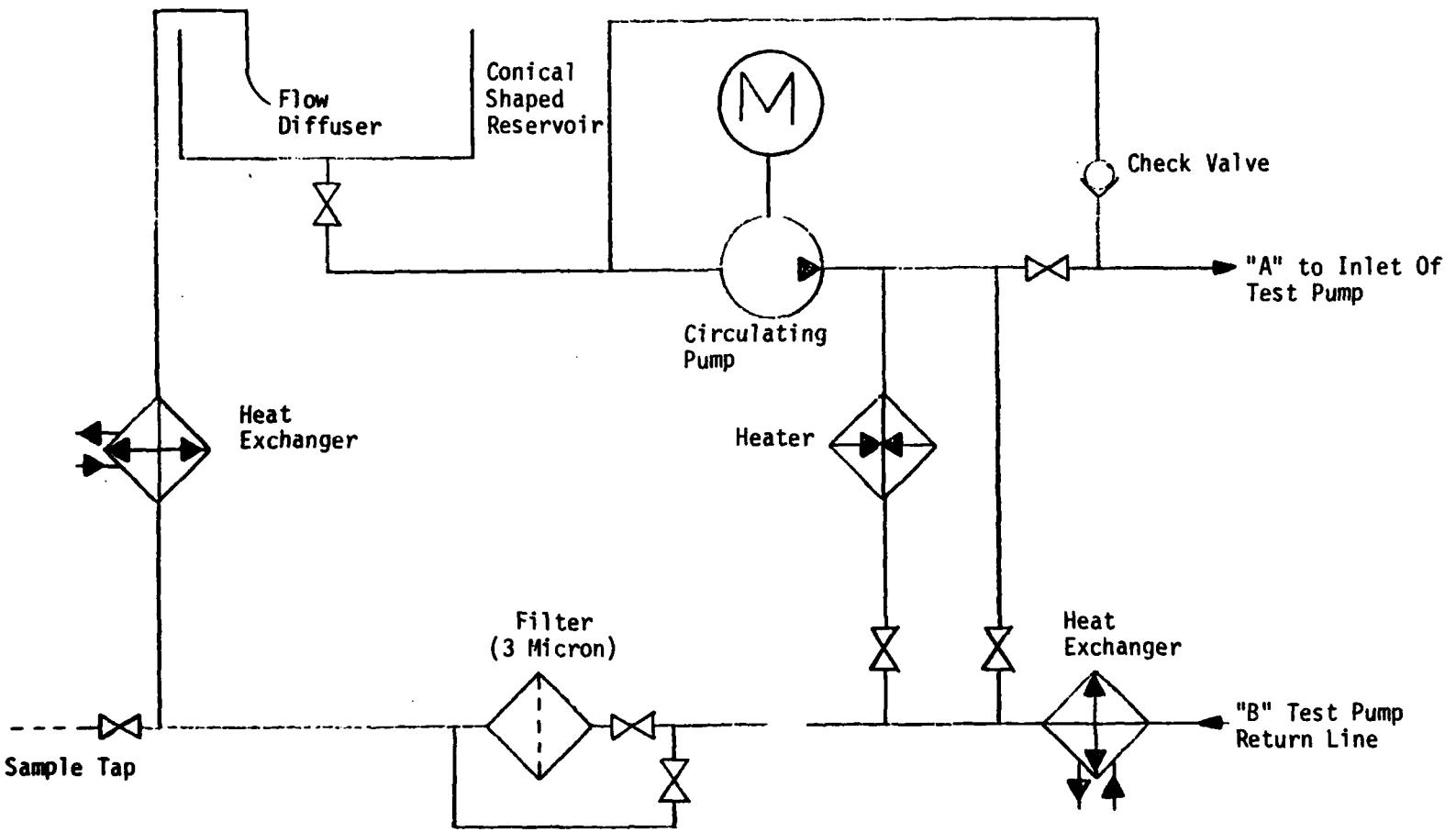


Data Acquisition System (DAS) and Supporting Instrumentation.

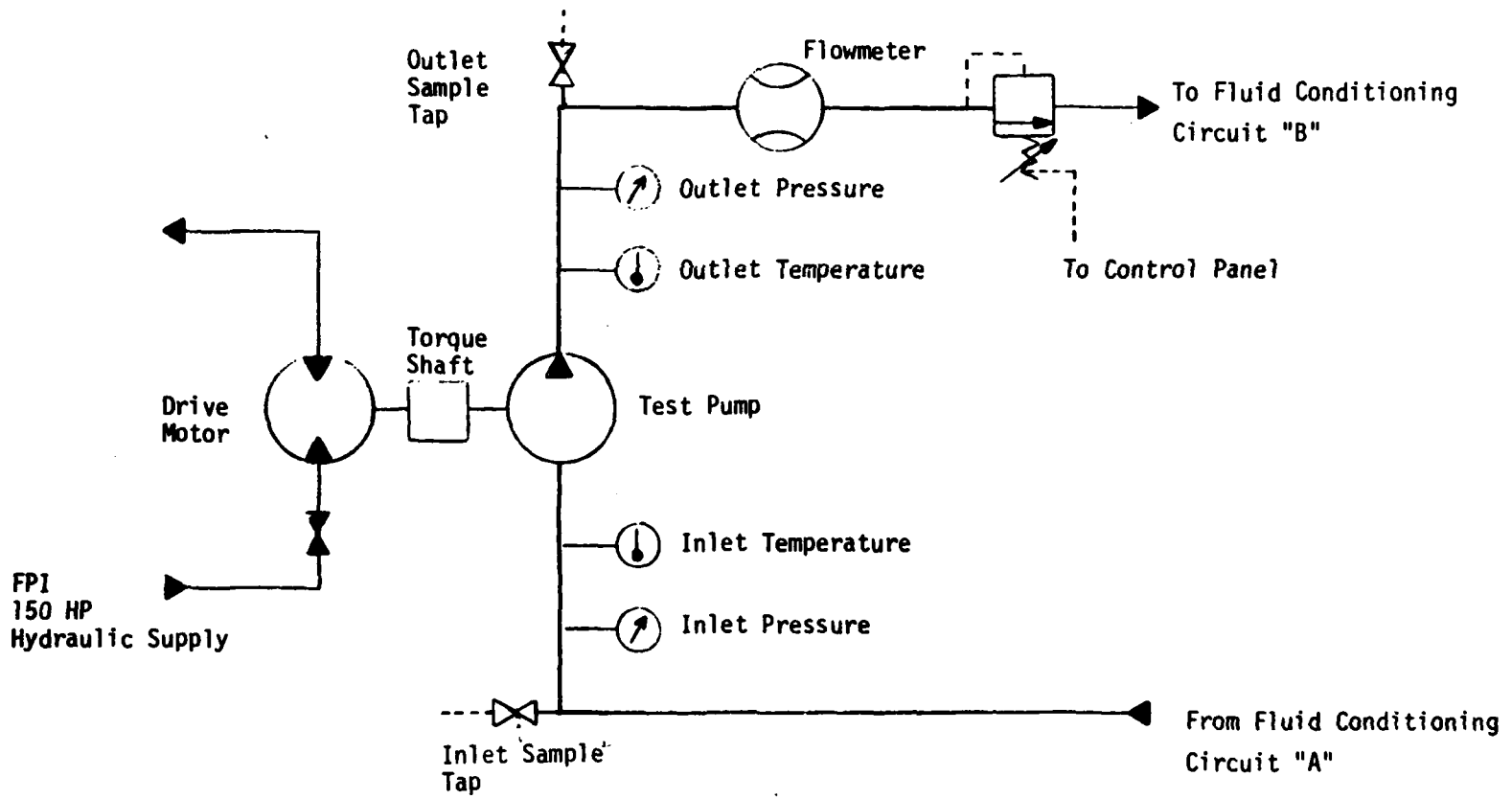
DAS is mounted in black cabinet with all connections in front. Torque shaft amplifier, Pace and Viatran pressure transducer power supplies and frequency counter used to monitor test pump RPM. Also shown are two frequency to voltage converters, and control box for 150 HP supply.

FLUID CONDITIONING CIRCUIT

BREAK-IN AND PERFORMANCE TESTS



BREAK-IN AND PERFORMANCE TEST CIRCUIT

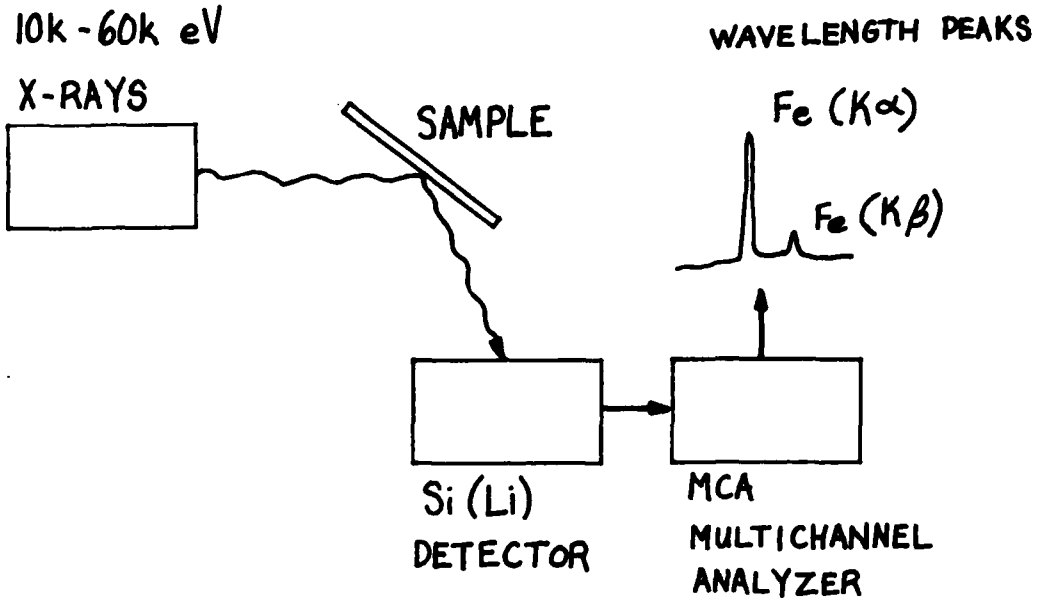


APPENDIX D

Detailed X-Ray Analysis and Gravimetric
Filter Patch Analysis Procedures

X-RAY FLUORESCENCE ANALYSIS

The x-ray fluorescence technique involves bombarding a sample with x-rays, thereby exciting the atoms present in the sample. The scattered x-rays include fluorescent x-rays from the excited atoms in the sample. Shown is a block of a typical emission system.



These fluorescent x-rays are sorted into various energy groups and displayed on the CRT of the (MCA) multi-channel analyzer. This screen can be precalibrated and through the use of a moveable cursor, the various wavelength peaks can be determined and identified. The spectrometer can be operated in an air path for all elements above Ar, but requires a vacuum or helium flush for the light elements. With a vacuum Si-Al-Mg, are about the lowest group of elements that one can easily detect.

From time to time we have had a need to look at metal particles in oil samples. One can also follow certain normal oil additives like S and Zn for build-up or fall off with some process, One can look at filter patch samples or directly at oil samples themselves. For very small sample amounts present, there is the problem of a signal to noise recovery of the sample. A fair amount of time has to go into "set-up". There are instruments that have attached microscopes that can allow one to focus down on a particular particle and do emission analysis on <u>that</u> particle or even on some small part of the particle. Our instrument is not of this type; we need to look at fluorescent x-rays from a fairly large region compared to the size of a single particle. This "large region" always involves other

things like oil, filler patch, etc.. These "other things" that are present add to what we would call our noise. In the event that the amount of sample present is very small, the background may give many more counts than the sample, and the sample x-rays are more or less lost in the statistical randomness of the background. One can play various games to reduce the background noise, like electronically subtracting the background if one can reproduce the background minus the sample on a separate sample holder. Various methods of sample preparation might be employed to reduce background noise.

X-RAY EMISSION ANALYSIS OF OIL SAMPLES

For the period of January to April 1983, we took x-ray emission data from a number of liquid oil and filter patch samples for the MSOE Fluid Power Institute. In the institute's laboratory, a pump was driven to higher and higher pressures until it was to fail. Our plan was to follow the break-up of the pump, as failure occured, with an elemental x-ray emission analysis. Data was recorded for a period of time, but the emission analysis portion of the test was terminated by the MSOE Fluid Power Institute prior to pump failure. Brian Batley, a technician at MSOE assisted with the data collection. No trends (changing concentrations of elements) were noted.

GRAVIMETRIC FILTER PATCH USING ANALYTICAL BALANCE

1. Determine initial mass of filter patch (0.45 micron Millipore filter patches were used).
2. Agitate oil samples in paint shaker for ten minutes.
3. Use Millipore filter patch apparatus cleaned in accordance with sample container method. NFPA/T2.9.2M-1972.
4. Deairate oil sample.
5. Rinse patch with filter agitene, place on filter base, and attatch funnel.
6. Place 25 ml. filtered agitene in funnel, add measured amount of oil, add 50 ml. filtered freon, and stir mixture.
7. Apply vacuum to filtering apparatus.
8. Rinse sides of funnel to wash down any residual oil.
9. Allow vacuum to operate until patch appears dry.
10. Transfer patch to a clean petri disk.
11. Place in 125°F oven for 12 hours to remove any moisture from the patch.
12. Use analytical balance to determine the final mass of the patch.

APPENDIX E

TABULATED AND GRAPHICAL DATA FROM BREAK-IN TEST

CYCLIC BREAK-IN TEST DATA
FOR PUMP NUMBER M1468 A

TIME MIN	OUTLET TEMP(F)	DIFF PRESS PSID	SPEED RPM	TORQUE IN-LB	FLOW GPM	OVER ALL EFF(%)	VOL EFF (%)	MECH EFF (%)
0.00	103.50	331.50	2705.00	207.40	31.05	67.50	95.89	70.47
0.53	104.00	527.70	2693.00	303.40	30.47	74.13	94.17	78.75
3.07	106.10	1203.15	2657.00	614.40	29.10	77.07	90.13	85.33
8.50	105.00	2474.21	2584.00	1203.00	27.21	76.30	84.04	90.78
9.10	103.20	3048.43	2550.00	1451.40	26.76	76.34	82.65	92.30

THREE HOUR PERFORMANCE TEST

PUMP NUMBER M1468A RUN AT RATED PRESSURE AND SPEED

TIME MIN	OUTLET TEMP(F)	DIFF PRESS PSID	TORQUE IN-LB	SPEED RPM	FLOW GPM	OVER ALL EFF(%)	VOL EFF (%)	MECH EFF (%)
0.00	168.60	3974.74	1435.60	2706.00	24.63	70.38	75.87	92.64
5.00	166.16	3959.79	1466.20	2703.00	24.16	69.05	74.52	92.64
10.00	165.10	3955.40	1377.40	2709.00	23.83	66.68	70.88	93.95
15.00	162.50	3950.48	1435.40	2706.00	23.35	67.08	71.96	93.21
20.00	162.70	3955.24	1435.60	2704.00	23.08	66.41	71.18	93.28
25.00	162.50	3956.18	1391.40	2707.00	21.98	63.47	67.70	93.67
30.00	162.20	3819.37	1431.60	2705.00	25.27	72.31	77.76	92.98
35.00	160.90	3816.73	1434.00	2701.00	25.30	72.50	78.18	92.74
40.00	163.40	3808.34	1425.60	2703.00	24.88	71.25	76.75	92.89
45.00	165.00	3808.21	1422.60	2707.00	25.07	71.80	77.24	92.98
50.00	163.80	3816.80	1430.80	2705.00	25.53	73.05	78.78	92.68
55.00	162.90	3814.21	1432.20	2706.00	25.50	72.91	78.57	92.78
60.00	161.70	3809.67	1433.40	2708.00	25.50	72.69	78.51	92.56
65.00	160.20	3814.30	1433.40	2707.00	25.19	71.90	77.68	92.72
70.00	161.10	3805.50	1426.80	2707.00	25.13	71.66	77.41	92.56
75.00	164.00	3801.78	1428.40	2709.00	25.18	72.22	77.51	93.17
80.00	163.40	3801.66	1423.80	2707.00	24.92	71.14	76.78	92.63
85.00	162.40	3801.58	1428.60	2706.00	24.97	71.41	76.65	93.15
90.00	161.30	3803.86	1426.20	2708.00	25.15	71.65	77.43	92.52
100.00	162.30	3825.39	1442.80	2704.00	25.25	74.84	80.94	92.44
105.00	161.80	3804.00	1443.20	2705.00	25.15	74.49	80.67	92.38
110.00	165.40	3814.10	1439.60	2707.00	25.07	74.14	80.31	92.38
115.00	164.90	3811.80	1437.80	2701.00	25.27	74.92	81.11	92.35
120.00	163.10	3808.66	1436.20	2706.00	25.22	74.64	80.80	92.35
125.00	163.20	3804.95	1432.60	2707.00	25.05	74.23	80.26	92.47
130.00	163.40	3807.74	1433.20	2705.00	25.04	73.87	79.96	92.37
135.00	163.40	3806.44	1431.00	2706.00	25.06	73.79	79.78	92.31
140.00	163.40	3806.80	1429.00	2706.00	25.04	73.84	79.81	92.43
145.00	162.00	3817.76	1446.40	2701.00	24.58	73.49	80.87	91.57
150.00	164.60	3816.59	1444.60	2705.00	24.42	73.00	81.46	92.06
155.00	163.40	3808.74	1440.60	2708.00	24.36	74.58	80.98	92.07
160.00	163.10	3803.81	1437.00	2706.00	24.17	74.28	80.51	92.15
165.00	163.20	3807.67	1435.20	2707.00	24.06	74.06	80.29	92.23
170.00	163.30	3801.37	1432.40	2710.00	24.02	73.98	80.07	92.37
175.00	163.50	3805.71	1433.00	2709.00	25.79	73.19	79.48	92.16
180.00	163.50	3809.84	1427.40	2706.00	25.68	72.85	78.98	92.32
185.00	163.20	3803.26	1418.80	2711.00	25.48	72.42	78.17	92.78

THE AVERAGE FLOW IS: 25.3063 GPM
THE AVERAGE SPEED IS: 2705.89 RPM
THE AVERAGE TORQUE IS: 1427.68 IN-LB

THREE HOUR PERFORMANCE TEST
CONTINUATION FOR PUMP M1468A

THE AVERAGE DIFFERENTIAL PRESSURE IS: 2999.58 PSID

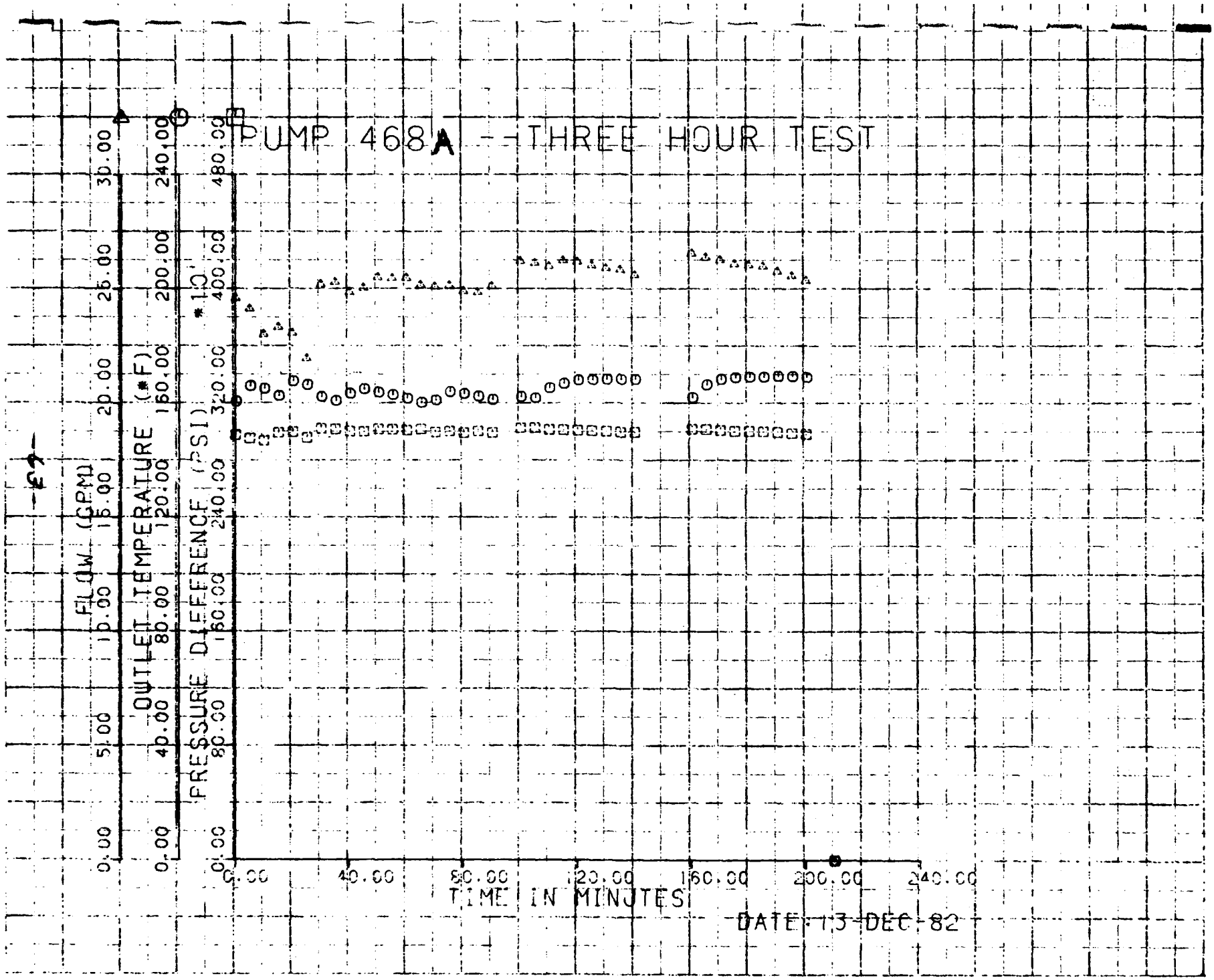
THE STANDARD DEVIATION OF THE:

MEASURED FLOW IS: 2.78769 GPM
MEASURED SPEED IS: 6.47407 RPM
MEASURED TORQUE IS: 37.5351 IN-LB
DIFFERENTIAL PRESSURE IS: 51.7881 PSID

THE MAX. OVER ALL EFFICIENCY IS: 75.4918
THE MIN. OVER ALL EFFICIENCY IS: 63.4222
THE AVERAGE OVER ALL EFFICIENCY IS: 72.2429

THE MAX. VOLUMETRIC EFFICIENCY IS: 82.0659
THE MIN. VOLUMETRIC EFFICIENCY IS 67.7006
THE AVERAGE VOLUMETERIC EFFICIENCY IS 77.9925

THE MAX. MECHANICAL EFFICIENCY IS 93.952
THE MIN. MECHANICAL EFFICIENCY IS 91.9743
THE AVERAGE MECHANICAL EFFICIENCY IS 92.6284


PUMP 468A -- THREE HOUR TEST
FLOW (GPM)
OUTLET TEMPERATURE (*F)
PRESSURE DIFFERENCE (PSI) *10
0.00
5.00
10.00
15.00
20.00
25.00
30.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00
0.00
80.00
160.00
240.00
320.00
400.00
480.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00
TIME IN MINUTES
DATE 13 DEC 82

CYCLIC BREAK-IN TEST DATA
FOR PUMP NUMBER M1468B

TIME MIN	OUTLET TEMP(F)	DIFF PRESS PSID	SPEED RPM	TORQUE IN-LB	ADJ FLOW GPM	OUTB BRG TEMP(%)	VOL EFF (%)	MECH EFF (%)
0.00	161.50	322.24	2498.00	285.00	31.50	67.25	97.31	69.18
0.33	163.00	569.93	2481.00	319.20	30.85	75.00	95.29	78.71
0.52	162.20	1104.20	2449.00	585.00	29.20	79.15	91.74	86.26
4.20	165.00	2383.27	2500.00	1154.00	27.50	77.50	85.10	91.00
5.43	169.00	3011.05	2548.00	1435.00	26.50	75.50	82.13	92.50

THREE HOUR PERFORMANCE TEST

PUMP NUMBER M1468 RUN AT RATED PRESSURE AND SPEED

TIME MIN	OUTLET TEMP(F)	DIFF PRESS PSID	TORQUE IN-LB	SPEED RPM	FLOW GPM	OVER ALL EFF(%)	VOL EFF (%)	MECH EFF (%)
0.00	171.70	3004.14	1427.70	2707.00	25.47	75.68	81.72	92.58
3.00	171.90	3008.16	1427.80	2706.00	25.47	75.57	81.56	92.64
8.00	171.90	2994.92	1423.40	2709.00	25.36	75.27	81.13	92.76
12.90	172.00	2995.92	1420.40	2709.00	25.21	75.04	80.69	92.99
17.90	171.60	2989.37	1418.80	2708.00	25.15	74.87	80.54	92.89
23.00	171.70	2988.24	1418.70	2710.00	25.96	74.46	79.70	93.42
28.00	172.10	2991.12	1413.60	2708.00	25.75	73.98	79.29	93.28
32.90	171.80	2975.92	1412.00	2712.00	25.58	73.89	78.65	92.91
38.00	172.90	2969.45	1400.00	2708.00	25.37	72.66	78.14	92.98
42.90	172.50	2991.16	1409.50	2713.00	25.32	72.89	77.84	93.54
47.90	172.80	2983.86	1407.80	2709.00	25.27	72.53	77.63	93.42
53.00	172.70	2985.78	1406.80	2716.00	25.27	72.68	77.58	93.56
57.90	173.00	2984.43	1405.20	2712.00	25.17	72.49	77.41	93.63
63.00	172.80	2984.28	1408.60	2716.00	25.31	72.58	77.70	93.48
67.90	172.90	2976.99	1406.20	2714.00	24.96	71.78	76.78	93.33
72.90	172.90	2988.50	1410.80	2718.00	25.12	71.79	77.07	93.14
78.00	173.00	2981.48	1405.40	2715.00	24.98	71.54	76.48	93.53
82.90	173.00	2977.31	1401.80	2719.00	25.13	72.17	77.07	93.63
88.00	173.30	2983.77	1414.40	2715.00	24.88	71.87	76.16	93.38
92.00	173.50	2988.24	1413.20	2716.00	24.94	71.69	76.56	93.53
97.90	173.60	2987.36	1413.20	2716.00	25.03	71.88	76.86	93.58
103.00	173.60	2987.15	1415.80	2715.00	24.96	71.57	76.67	93.33
107.90	173.70	2987.33	1412.80	2716.00	24.86	71.41	76.34	93.53
112.90	173.70	2984.32	1413.20	2713.00	24.88	71.46	76.49	93.41
118.00	173.50	2989.65	1409.80	2716.00	24.91	71.76	76.49	93.88
122.90	171.00	2986.04	1415.60	2714.00	24.88	71.12	76.45	93.01
128.00	173.70	2994.68	1414.80	2717.00	24.76	70.93	76.99	93.30
133.00	173.90	2986.20	1414.60	2715.00	24.87	71.33	76.37	93.38
137.90	173.80	2994.41	1414.80	2717.00	25.06	71.81	76.91	93.36
143.00	172.70	3004.39	1415.00	2712.00	25.09	72.23	77.15	93.68
147.90	173.00	3004.42	1415.00	2717.00	25.23	72.51	77.45	93.61
152.90	173.50	3003.22	1417.40	2714.00	25.09	72.01	77.00	93.41
158.00	173.30	3004.00	1416.80	2718.00	25.00	71.82	76.71	93.35
162.90	172.90	3018.48	1415.00	2714.00	25.07	72.26	77.03	93.79
168.00	172.60	3001.50	1411.20	2717.00	25.05	72.11	76.88	93.77
173.00	173.10	2992.27	1415.40	2714.00	24.90	71.45	76.65	93.20
177.90	173.00	3006.23	1414.40	2720.00	25.18	72.11	76.97	93.67

THE AVERAGE FLOW IS: 25.275 GPM
THE AVERAGE SPEED IS: 2713.65 RPM
THE AVERAGE TORQUE IS: 1413.39 IN-LB

THREE HOUR PERFORMANCE TEST
CONTINUATION FOR PUMP M1468 3

THE AVERAGE DIFFERENTIAL PRESSURE IS: 2992.56 PSID

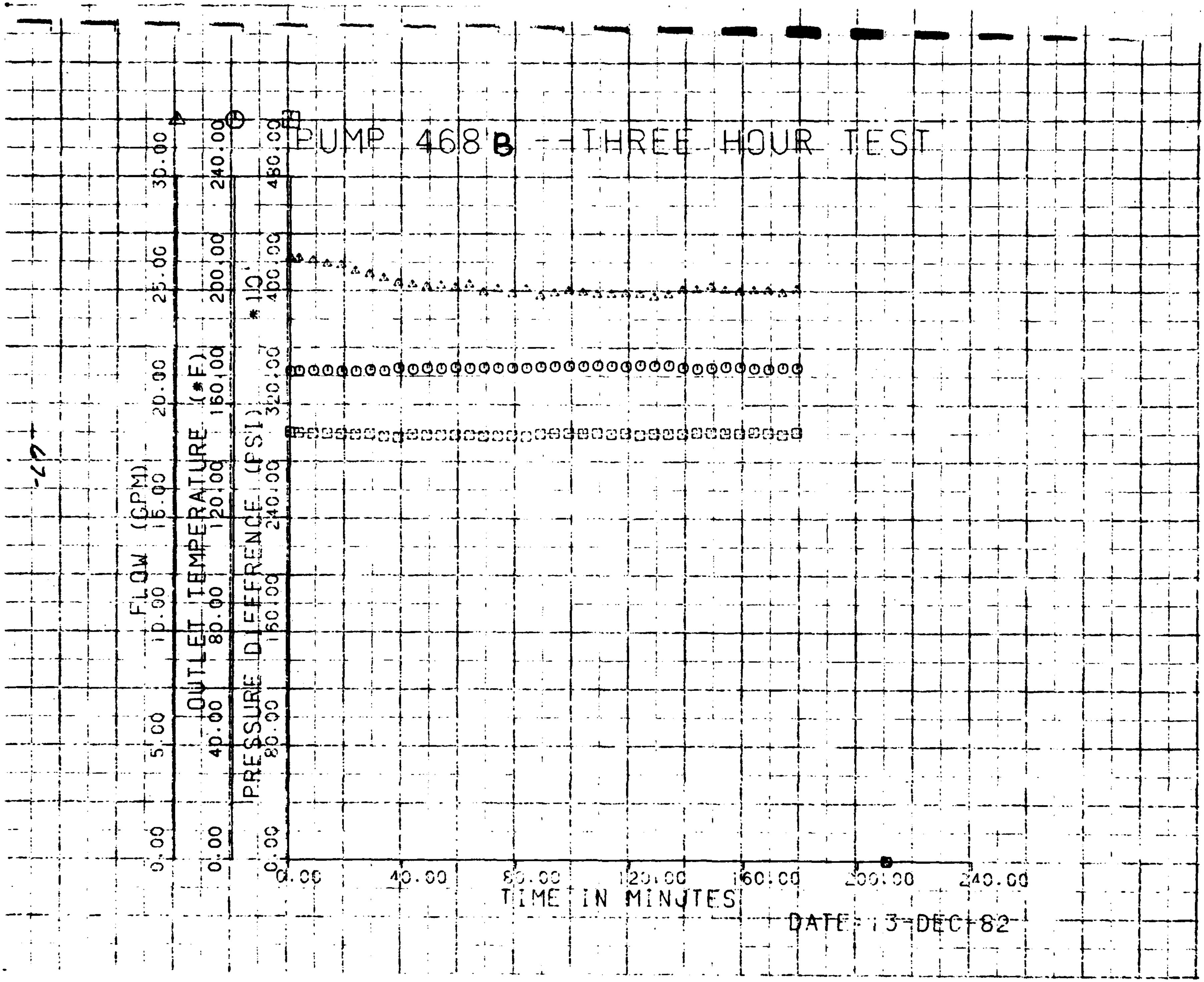
THE STANDARD DEVIATION OF THE:

MEASURED FLOW IS: 1.3164 GPM
MEASURED SPEED IS: 9.78195 RPM
MEASURED TORQUE IS: 15.0104 IN-LB
DIFFERENTIAL PRESSURE IS: 25.6603 PSID

THE MAX. OVER ALL EFFICIENCY IS: 75.6924
THE MIN. OVER ALL EFFICIENCY IS: 70.9252
THE AVERAGE OVER ALL EFFICIENCY IS: 72.5128

THE MAX. VOLUMETRIC EFFICIENCY IS: 81.5629
THE MIN. VOLUMETRIC EFFICIENCY IS 75.9934
THE AVERAGE VOLUMETERIC EFFICIENCY IS 77.6746

THE MAX. MECHANICAL EFFICIENCY IS 93.802
THE MIN. MECHANICAL EFFICIENCY IS 92.6352
THE AVERAGE MECHANICAL EFFICIENCY IS 93.3434


PUMP 468 B - THREE HOUR TEST
FLOW (GPM)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
OUTLET TEMPERATURE (*F)
0.00
40.00
80.00
120.00
160.00
200.00
240.00
PRESSURE DIFFERENCE (PSI) *10
0.00
80.00
160.00
240.00
320.00
400.00
480.00
TIME IN MINUTES
0.00
40.00
80.00
120.00
160.00
200.00
240.00
DATE 13-DEC-82

CYCLIC BREAK-IN TEST DATA
FOR PUMP NUMBER M1468C

TIME MIN	OUTLET TEMP(F)	DIFF PRESS PSID	SPEED RPM	TORQUE IN-LB	ADJ FLOW GPM	OUTB OIL FIT(%)	VOL FIT (%)	MECH FIT (%)
0.00	150.00	333.91	2700.00	210.00	31.34	67.02	96.81	69.65
0.75	161.00	582.32	2695.00	307.00	30.70	74.51	95.86	78.37
2.00	165.00	1108.13	2700.00	483.40	34.83	93.41	107.59	86.81
4.00	168.00	2306.70	2695.00	1153.40	27.01	77.00	85.20	91.73
4.83	170.00	2994.00	2550.00	1473.40	20.04	70.39	80.20	92.75

THREE HOUR PERFORMANCE TEST

PUMP NUMBER N1468C RUN AT RATED PRESSURE AND SPEED

TIME MIN	OUTLET TEMP (F)	DIFF PRESS PSID	TORQUE IN-LB	SPEED RPM	FLOW GPM	OVER ALL EFF (%)	VOL EFF (%)	MECH EFF (%)
0.00	171.50	3046.74	1431.58	2700.00	26.71	76.19	89.73	97.64
5.00	171.50	3047.81	1433.20	2714.00	26.68	76.07	89.99	97.59
9.99	172.00	3043.06	1429.58	2716.00	26.66	76.01	89.86	97.66
15.00	172.50	3044.00	1430.00	2718.00	26.63	76.03	89.83	97.63
20.00	172.25	3042.50	1429.58	2714.00	26.53	75.99	89.79	97.58
24.98	172.50	3044.56	1427.58	2723.00	26.53	75.94	89.76	97.53
29.97	172.50	3043.03	1425.58	2717.00	26.43	75.80	89.73	97.55
35.00	172.25	3046.15	1429.00	2723.00	26.48	74.83	88.84	97.56
40.00	172.50	3041.46	1424.20	2721.00	26.37	75.00	88.81	97.91
44.98	172.50	3041.84	1423.40	2726.00	26.45	75.25	88.97	97.97
49.98	172.50	3039.13	1427.20	2723.00	26.46	75.09	89.04	97.64
54.98	172.25	3041.39	1424.00	2726.00	26.43	75.15	88.86	97.97
59.99	172.50	3041.68	1427.80	2725.00	26.35	75.00	88.67	98.01
65.00	172.50	3039.72	1426.40	2727.00	26.41	74.88	88.75	97.71
69.98	171.50	3046.77	1425.80	2726.00	26.57	75.54	89.27	97.94
74.98	172.00	3046.12	1425.40	2726.00	26.46	75.25	88.95	97.94
80.00	172.00	3044.47	1427.60	2728.00	26.53	75.24	89.09	97.78
85.00	172.00	3039.58	1423.60	2726.00	26.42	75.00	88.82	97.89
89.98	172.50	3045.93	1428.20	2729.00	26.54	75.26	89.10	97.79
94.98	173.00	3044.19	1426.20	2724.00	26.46	75.24	89.01	97.86
100.00	172.50	3044.60	1427.40	2729.00	26.54	75.27	89.10	97.88
105.00	172.50	3041.99	1424.80	2727.00	26.49	75.26	89.01	97.89
109.98	172.40	3044.28	1427.20	2731.00	26.57	75.29	89.12	97.88
115.00	172.40	3041.81	1426.40	2726.00	26.48	75.12	88.96	97.78
120.00	172.50	3040.97	1425.40	2731.00	26.55	75.31	89.08	97.88
124.98	172.10	3043.06	1426.00	2728.00	26.47	75.14	88.97	97.84
129.98	172.60	3043.84	1427.20	2731.00	26.51	75.17	88.95	97.79
135.00	172.20	3044.31	1425.00	2727.00	26.44	75.16	88.85	97.95
140.00	172.50	3041.53	1425.60	2732.00	26.58	75.67	88.68	97.81
144.98	172.10	3044.84	1424.40	2730.00	26.49	75.29	88.91	97.84
149.98	172.10	3044.31	1423.40	2731.00	26.47	75.23	88.84	97.86
155.00	171.80	3040.26	1426.60	2730.00	26.51	75.35	88.99	97.78
160.00	171.80	3045.39	1425.40	2730.00	26.47	75.17	88.86	97.85
164.98	172.00	3044.37	1426.00	2730.00	26.50	75.17	88.96	97.83
169.98	172.00	3043.65	1427.60	2730.00	26.48	74.98	88.63	97.76
175.00	171.90	3043.45	1426.40	2730.00	26.47	75.06	88.85	97.83

THE AVERAGE FLOW IS: 26.4957 GPM
THE AVERAGE SPEED IS: 2725.44 RPM
THE AVERAGE TORQUE IS: 1426.61 IN-LB

THREE HOUR PERFORMANCE TEST
CONTINUATION FOR PUMP M1468C

THE AVERAGE DIFFERENTIAL PRESSURE IS: 3003.46 PSID

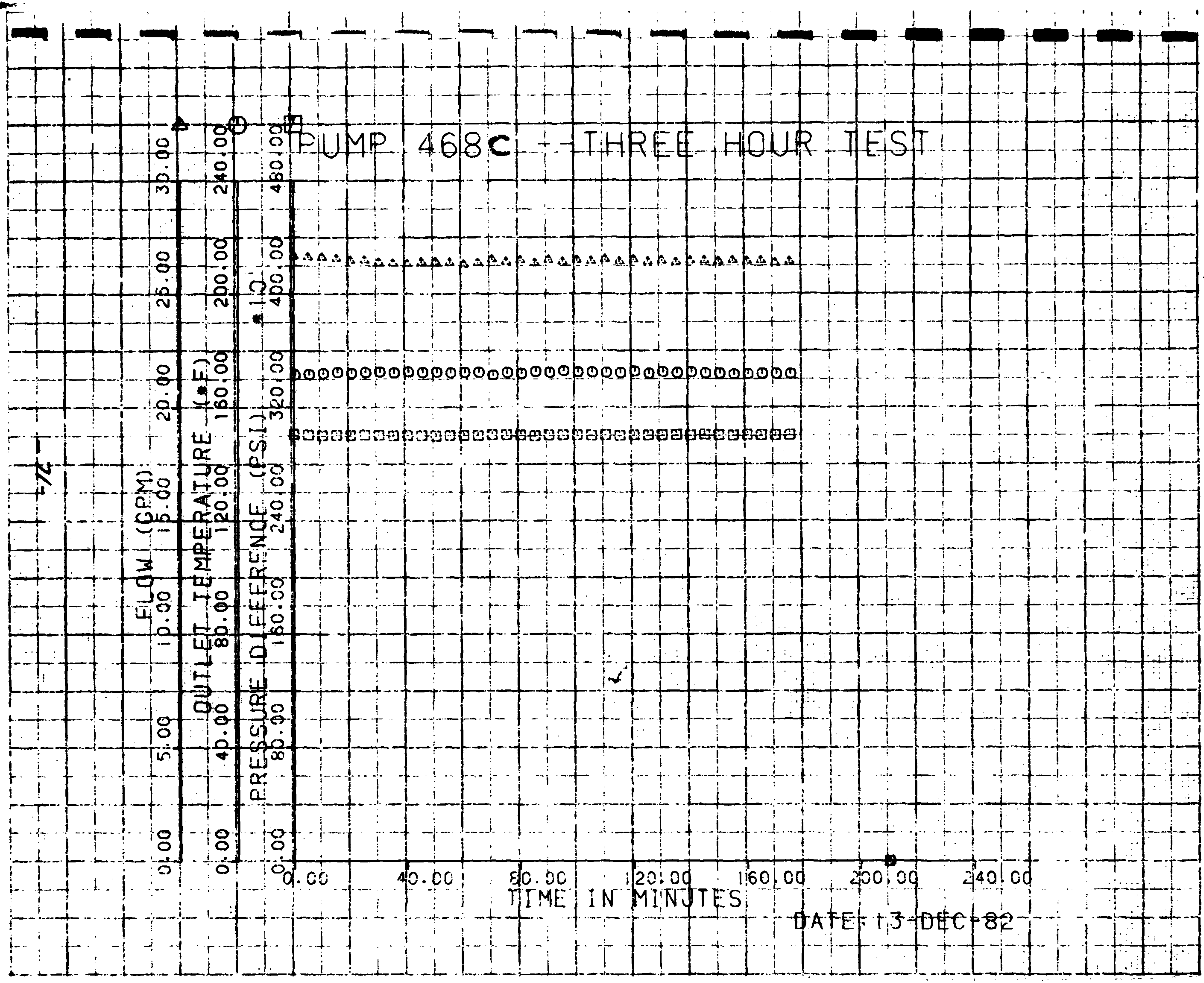
THE STANDARD DEVIATION OF THE:

MEASURED FLOW IS: .216775 GPM
MEASURED SPEED IS: 15.0525 RPM
MEASURED TORQUE IS: 6.16633 IN-LB
DIFFERENTIAL PRESSURE IS: 5.85274 PSID

THE MAX. OVER ALL EFFICIENCY IS: 76.1935
THE MIN. OVER ALL EFFICIENCY IS: 74.8032
THE AVERAGE OVER ALL EFFICIENCY IS: 75.2592

THE MAX. VOLUMETRIC EFFICIENCY IS: 82.233
THE MIN. VOLUMETRIC EFFICIENCY IS 80.6239
THE AVERAGE VOLUMETERIC EFFICIENCY IS 81.0724

THE MAX. MECHANICAL EFFICIENCY IS 93.0501
THE MIN. MECHANICAL EFFICIENCY IS 92.5215
THE AVERAGE MECHANICAL EFFICIENCY IS 92.8148


PUMP 468C - THREE HOUR TEST
FLOW (GPM)
0.00 5.00 10.00 15.00 20.00 25.00 30.00
OUTLET TEMPERATURE (*F)
0.00 40.00 80.00 120.00 160.00 200.00 240.00
PRESSURE DIFFERENCE (PSI) *10'
0.00 80.00 160.00 240.00 320.00 400.00 480.00
0.00 40.00 80.00 120.00 160.00 200.00 240.00
TIME IN MINUTES
DATE 13-DEC-82

THREE HOUR PERFORMANCE TEST

PUMP NUMBER M1468D RUN AT RATED PRESSURE AND SPEED

TIME MIN	OUTLET TEMP(F)	OUT PRESS PSID	TORQUE IN-LB	SPEED RPM	FLOW GPM	OUTER OIL TEMP(F)	VOL EFF (%)	MECH EFF (%)
0.00	163.10	605.56	334.59	2697.00	30.58	75.21	94.31	79.74
4.50	162.30	605.53	335.46	2696.00	30.49	75.07	94.36	79.59
10.00	161.50	605.84	335.46	2694.00	30.58	75.10	94.41	79.53
14.50	160.90	605.74	335.59	2698.00	30.48	75.43	94.21	80.05
20.00	160.00	610.71	336.46	2697.00	30.46	75.48	94.19	80.03
24.50	159.20	606.25	335.59	2696.00	30.44	75.20	94.16	79.85
30.00	159.30	606.73	337.20	2698.00	30.44	75.03	94.18	79.77
34.50	159.20	611.07	338.59	2698.00	30.44	74.89	94.08	79.51
40.00	159.30	611.11	337.00	2700.00	30.47	75.18	94.03	79.94
44.50	159.00	606.96	336.20	2702.00	30.58	74.73	94.13	79.38
50.00	159.40	606.38	337.00	2700.00	30.52	74.38	94.26	78.98
54.50	163.40	607.69	335.40	2703.00	30.52	74.99	94.16	79.02
60.00	163.20	608.01	334.40	2703.00	30.58	75.29	94.11	79.99
64.50	162.30	606.66	335.59	2704.00	30.54	74.78	94.19	79.38
70.00	161.50	606.23	336.20	2704.00	30.51	75.00	94.11	79.77
74.50	160.40	606.44	337.00	2703.00	30.54	75.07	94.27	79.04
80.00	160.00	601.14	338.40	2702.00	30.53	74.25	94.12	78.89
84.50	159.00	602.51	338.00	2704.00	30.51	74.36	94.18	79.01
90.00	158.10	604.24	339.59	2705.00	30.58	74.71	94.04	79.43
94.50	158.20	601.98	338.00	2705.00	30.51	74.26	94.07	78.93
100.00	158.20	599.18	337.40	2700.00	30.51	74.73	94.18	79.34
104.50	157.70	598.24	337.40	2700.00	30.51	74.48	94.00	79.21
110.00	157.00	598.97	337.00	2704.00	30.51	74.56	94.11	79.21
114.50	157.00	599.26	335.00	2705.00	30.57	74.71	94.09	79.39
120.00	157.40	598.58	337.40	2707.00	30.56	74.02	94.14	79.26
124.50	157.00	594.71	336.20	2704.00	30.48	74.38	94.01	79.02
130.00	157.00	598.79	337.00	2700.00	30.52	74.08	94.14	79.23
134.50	156.50	598.77	336.20	2704.00	30.50	74.43	94.18	79.00
140.00	156.90	598.94	336.00	2700.00	30.54	74.58	94.12	79.23
144.50	156.30	599.46	336.00	2700.00	30.53	74.88	94.00	79.17
150.00	156.00	598.04	336.00	2704.00	30.59	74.93	94.12	79.08
154.50	156.00	598.65	336.00	2708.00	30.55	74.17	94.00	78.82
160.00	155.20	601.48	338.00	2704.00	30.56	74.34	94.23	78.87
164.50	155.30	598.22	336.20	2702.00	30.57	74.07	94.16	78.78
170.00	155.00	601.95	339.00	2702.00	30.54	74.50	94.18	79.18
174.50	155.00	605.87	338.20	2705.00	30.53	74.88	94.13	79.45
180.00	155.30	599.07	337.40	2700.00	30.54	74.08	94.04	79.53

THE AVERAGE FLOW IS: 30.5116 GPM
THE AVERAGE SPEED IS: 2702.89 RPM
THE AVERAGE TORQUE IS: 330.184 IN-LB

THREE HOUR PERFORMANCE TEST
CONTINUATION FOR PUMP M1468D

THE AVERAGE DIFFERENTIAL PRESSURE IS: 594.757 PSID

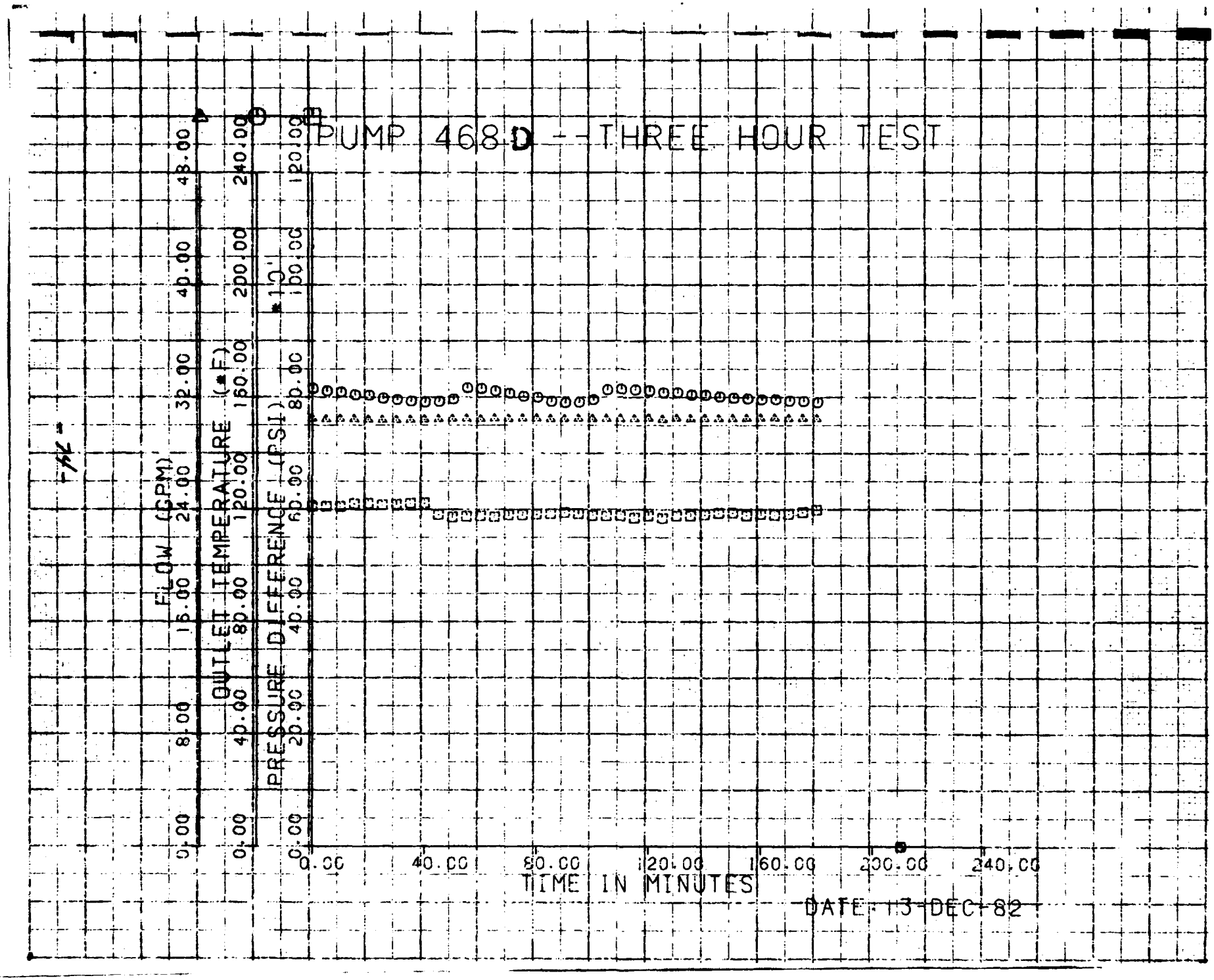
THE STANDARD DEVIATION OF THE:

MEASURED FLOW IS: .0872964 GPM
MEASURED SPEED IS: 9.99567 RPM
MEASURED TORQUE IS: 10.5606 IN-LB
DIFFERENTIAL PRESSURE IS: 22.7023 PSID

THE MAX. OVER ALL EFFICIENCY IS: 75.4316
THE MIN. OVER ALL EFFICIENCY IS: 74.169
THE AVERAGE OVER ALL EFFICIENCY IS: 74.7677

THE MAX. VOLUMETRIC EFFICIENCY IS: 94.4105
THE MIN. VOLUMETRIC EFFICIENCY IS 94.0058
THE AVERAGE VOLUMETERIC EFFICIENCY IS 94.1388

THE MAX. MECHANICAL EFFICIENCY IS 80.0503
THE MIN. MECHANICAL EFFICIENCY IS 78.8211
THE AVERAGE MECHANICAL EFFICIENCY IS 79.4098


PUMP 468D -- THREE HOUR TEST
FLOW (GPM)
OUTLET TEMPERATURE (°F)
PRESSURE DIFFERENCE (PSI)
0.00
8.00
16.00
24.00
32.00
40.00
48.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00
TIME IN MINUTES
DATE: 13-DEC-82

THREE HOUR PERFORMANCE TEST

PUMP NUMBER M1468E RUN AT RATED PRESSURE AND SPEED

TIME MIN	OUTLET TEMP(F)	DIFF PRESS PSID	TORQUE IN-LB	SPEED RPM	FLOW GPM	OUTER RAT TEMP(%)	VOL EFF (%)	MECH EFF (%)
0.00	161.00	599.10	334.00	2704.00	30.83	75.00	95.00	78.69
5.00	160.50	593.77	331.00	2701.00	30.79	75.20	95.00	79.00
10.00	159.70	593.00	331.00	2700.00	30.77	74.94	95.03	78.95
15.00	159.00	589.20	330.40	2697.00	30.70	74.81	95.12	78.83
20.00	159.00	591.93	330.70	2700.00	30.79	75.16	95.09	79.03
25.00	159.30	590.77	330.00	2700.00	30.79	74.81	95.11	78.84
30.00	159.50	591.37	329.00	2699.00	30.75	75.16	95.00	79.10
35.00	160.20	597.40	327.20	2700.00	30.78	75.21	95.01	79.15
40.00	160.40	597.49	327.00	2701.00	30.77	75.00	94.95	79.00
45.00	160.70	598.05	328.00	2700.00	30.78	75.29	95.00	79.24
50.00	161.20	598.00	327.00	2703.00	30.70	75.34	94.91	79.30
55.00	161.20	599.81	327.00	2701.00	30.75	75.41	94.95	79.41
60.00	162.20	598.43	326.20	2704.00	30.70	75.50	94.92	79.53
65.00	162.30	598.90	326.00	2703.00	30.73	75.53	94.81	79.65
70.00	162.60	599.34	327.40	2700.00	30.77	75.20	94.83	79.36
75.00	162.90	599.07	329.00	2704.00	30.73	74.74	94.77	78.85
80.00	161.90	591.00	329.00	2702.00	30.71	75.16	94.78	79.20
85.00	159.70	591.69	330.60	2705.00	30.68	74.67	94.59	78.93
90.00	157.50	594.94	328.20	2704.00	30.71	75.71	94.72	79.92
95.00	157.40	598.19	330.40	2704.00	30.72	74.61	94.73	78.75
100.00	157.50	591.36	329.40	2705.00	30.71	74.93	94.64	79.15
105.00	157.30	592.73	327.80	2702.00	30.74	75.63	94.80	79.77
110.00	157.80	593.84	327.80	2705.00	30.73	75.57	94.73	79.70
115.00	158.10	597.15	330.60	2704.00	30.74	74.87	94.88	78.96
120.00	158.40	599.09	330.00	2703.00	30.78	74.64	94.71	78.88
125.00	158.70	593.43	330.80	2706.00	30.75	74.50	94.77	78.63
130.00	158.20	591.78	329.20	2703.00	30.74	75.15	94.89	79.24
135.00	160.00	591.07	331.00	2704.00	30.73	74.77	94.77	78.83
140.00	160.10	591.70	330.00	2705.00	30.71	74.65	94.66	78.86
145.00	160.50	599.03	331.00	2705.00	30.73	74.44	94.74	78.76
150.00	161.40	598.65	329.60	2702.00	30.74	74.85	94.78	79.03
155.00	161.70	598.60	331.00	2704.00	30.74	74.33	94.68	78.48
160.00	162.50	598.92	330.20	2702.00	30.73	74.78	94.67	78.98
165.00	162.50	592.84	332.20	2705.00	30.68	74.48	94.55	78.67
170.00	161.00	594.92	330.40	2704.00	30.67	75.00	94.57	79.30
175.00	159.00	594.99	329.60	2705.00	30.67	75.73	94.59	79.58
180.00	157.40	595.80	332.60	2704.00	30.66	74.59	94.55	78.87

THE AVERAGE FLOW IS: 30.7351 GPM
THE AVERAGE SPEED IS: 2703.19 RPM
THE AVERAGE TORQUE IS: 329.687 IN-LB

THREE HOUR PERFORMANCE TEST
CONTINUATION FOR PUMP M1468E

THE AVERAGE DIFFERENTIAL PRESSURE IS: 591.424 PSID

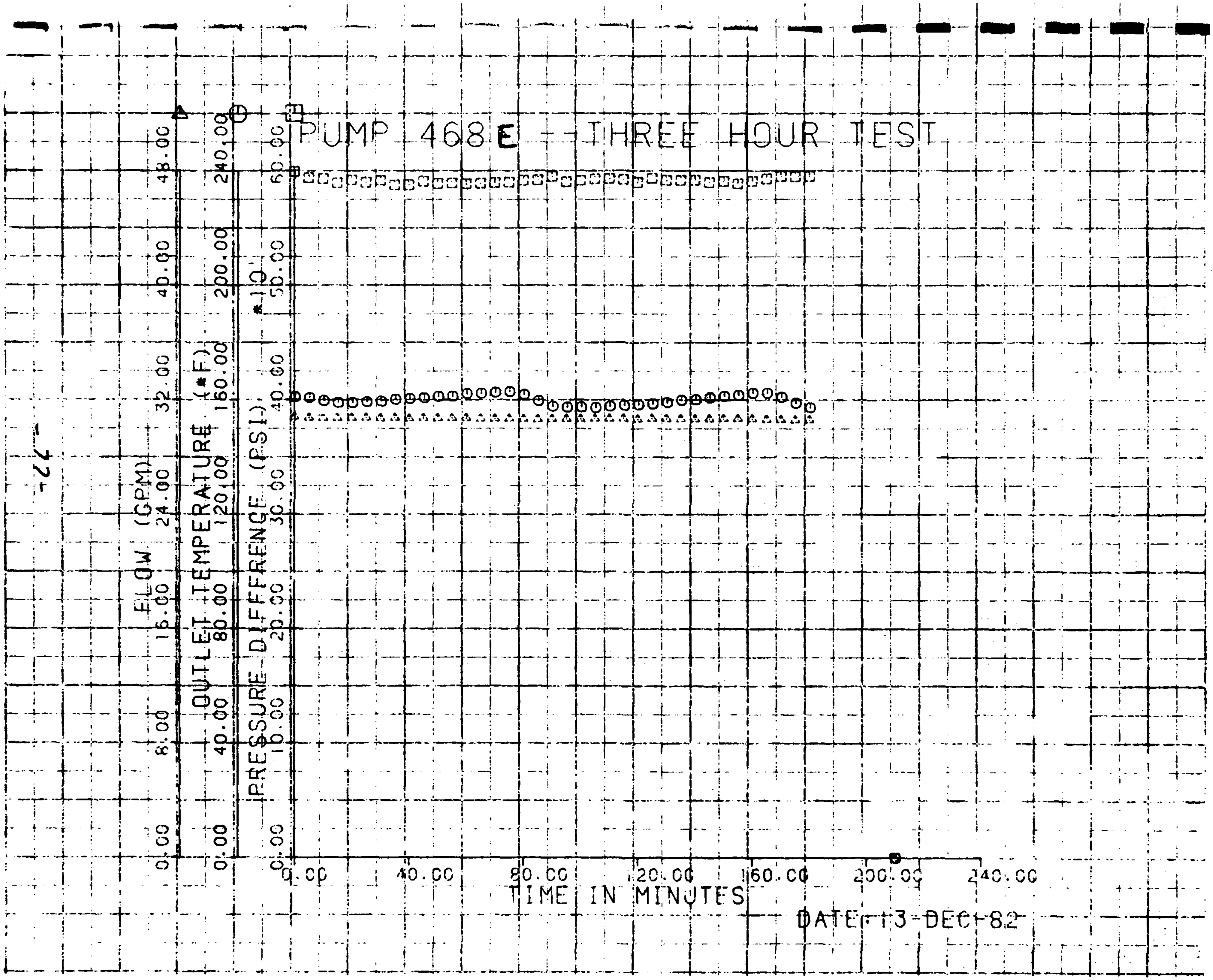
THE STANDARD DEVIATION OF THE:

MEASURED FLOW IS: .104487 GPM
MEASURED SPEED IS: 6.06095 RPM
MEASURED TORQUE IS: 5.16223 IN-LB
DIFFERENTIAL PRESSURE IS: 6.61879 PSID

THE MAX. OVER ALL EFFICIENCY IS: 75.7098
THE MIN. OVER ALL EFFICIENCY IS: 74.3335
THE AVERAGE OVER ALL EFFICIENCY IS: 75.001

THE MAX. VOLUMETRIC EFFICIENCY IS: 95.1249
THE MIN. VOLUMETRIC EFFICIENCY IS 94.5157
THE AVERAGE VOLUMETERIC EFFICIENCY IS 94.8182

THE MAX. MECHANICAL EFFICIENCY IS 79.9159
THE MIN. MECHANICAL EFFICIENCY IS 78.3968
THE AVERAGE MECHANICAL EFFICIENCY IS 79.0869


PUMP 468 E - THREE HOUR TEST
FLOW (GPM)
0.00
8.00
16.00
24.00
32.00
40.00
48.00
OUTLET TEMPERATURE (*F)
0.00
40.00
80.00
120.00
160.00
200.00
240.00
PRESSURE DIFFERENCE (PSI) *10
0.00
10.00
20.00
30.00
40.00
50.00
60.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00
TIME IN MINUTES
DATE 13-DEC-82

THREE HOUR PERFORMANCE TEST

PUMP NUMBER M1468F RUN AT RATED PRESSURE AND SPEED

TIME MIN	OUTLET TEMP(F)	DIFF PRESS PSID	TORQUE IN-LB	SPEED RPM	FLOW GPM	OUTER RTI TEMP(F)	VOL EFF (%)	MECH EFF (%)
0.00	164.90	564.53	329.00	2700.00	31.00	76.25	95.93	79.47
5.00	163.00	565.75	331.40	2700.00	31.00	75.97	95.85	79.25
10.00	158.90	568.59	332.40	2700.00	31.01	76.04	95.71	79.43
15.00	158.20	(00.01	332.00	2700.00	31.10	76.29	95.84	79.59
20.00	159.40	567.87	334.00	2705.00	31.00	75.40	95.74	78.81
25.00	160.00	567.78	332.20	2707.00	31.11	76.04	95.84	79.33
30.00	161.50	(00.98	333.00	2700.00	31.13	76.20	95.83	79.50
35.00	162.10	(00.94	332.20	2700.00	31.09	76.45	95.84	79.25
40.00	162.50	(00.70	334.20	2700.00	31.10	75.41	95.73	78.77
45.00	160.00	(00.65	333.00	2707.00	31.02	76.01	95.57	79.52
50.00	157.70	(03.70	334.20	2700.00	31.00	76.24	95.78	79.65
55.00	157.40	(00.44	333.60	2700.00	31.11	76.00	95.76	79.30
60.00	157.90	(00.01	332.00	2707.00	31.00	76.25	95.78	79.50
65.00	158.50	(02.50	334.00	2700.00	31.13	76.04	95.83	79.34
70.00	159.10	(02.00	334.00	2707.00	31.10	75.71	95.69	79.00
75.00	159.80	(00.45	334.60	2700.00	31.11	75.78	95.77	79.11
80.00	160.40	(00.50	333.00	2700.00	31.00	76.07	95.67	79.50
85.00	161.20	568.91	332.60	2700.00	31.03	75.99	95.69	79.38
90.00	161.00	566.81	332.60	2710.00	31.10	75.63	95.69	79.00
95.00	162.40	(00.00	334.20	2700.00	30.97	75.59	95.39	79.16
100.00	162.00	567.54	334.00	2700.00	31.00	74.90	95.60	78.46
105.00	162.50	(00.00	333.00	2700.00	30.97	75.64	95.33	79.36
110.00	160.20	569.40	333.20	2707.00	30.93	75.57	95.27	79.31
115.00	159.20	(02.22	334.00	2700.00	30.99	75.67	95.41	79.30
120.00	157.50	(01.30	332.20	2700.00	31.00	75.11	95.51	78.62
125.00	157.40	(02.44	334.40	2700.00	31.01	75.80	95.45	79.42
130.00	157.70	569.63	332.20	2710.00	30.99	75.21	95.35	78.86
135.00	159.30	(01.70	334.40	2700.00	30.97	75.65	95.36	79.31
140.00	159.70	(04.07	333.40	2710.00	31.00	76.27	95.47	79.00
145.00	159.40	569.25	334.40	2700.00	30.95	75.77	95.26	79.00
150.00	159.00	569.39	334.00	2700.00	30.96	75.23	95.30	78.53
155.00	160.00	(03.11	333.00	2700.00	30.93	75.91	95.23	79.20
160.00	161.20	566.41	333.40	2700.00	30.95	75.17	95.31	78.86
165.00	161.00	(01.04	334.20	2710.00	30.96	75.66	95.20	79.39
170.00	162.20	568.65	332.40	2700.00	30.97	75.23	95.34	79.42
175.00	162.00	(01.39	332.00	2711.00	30.93	75.13	95.14	79.55

THE AVERAGE FLOW IS: 31.0313 GPM
THE AVERAGE SPEED IS: 2707.78 RPM
THE AVERAGE TORQUE IS: 333.789 IN-LB

THREE HOUR PERFORMANCE TEST
CONTINUATION FOR PUMP M1468F

THE AVERAGE DIFFERENTIAL PRESSURE IS: 600.083 PSID

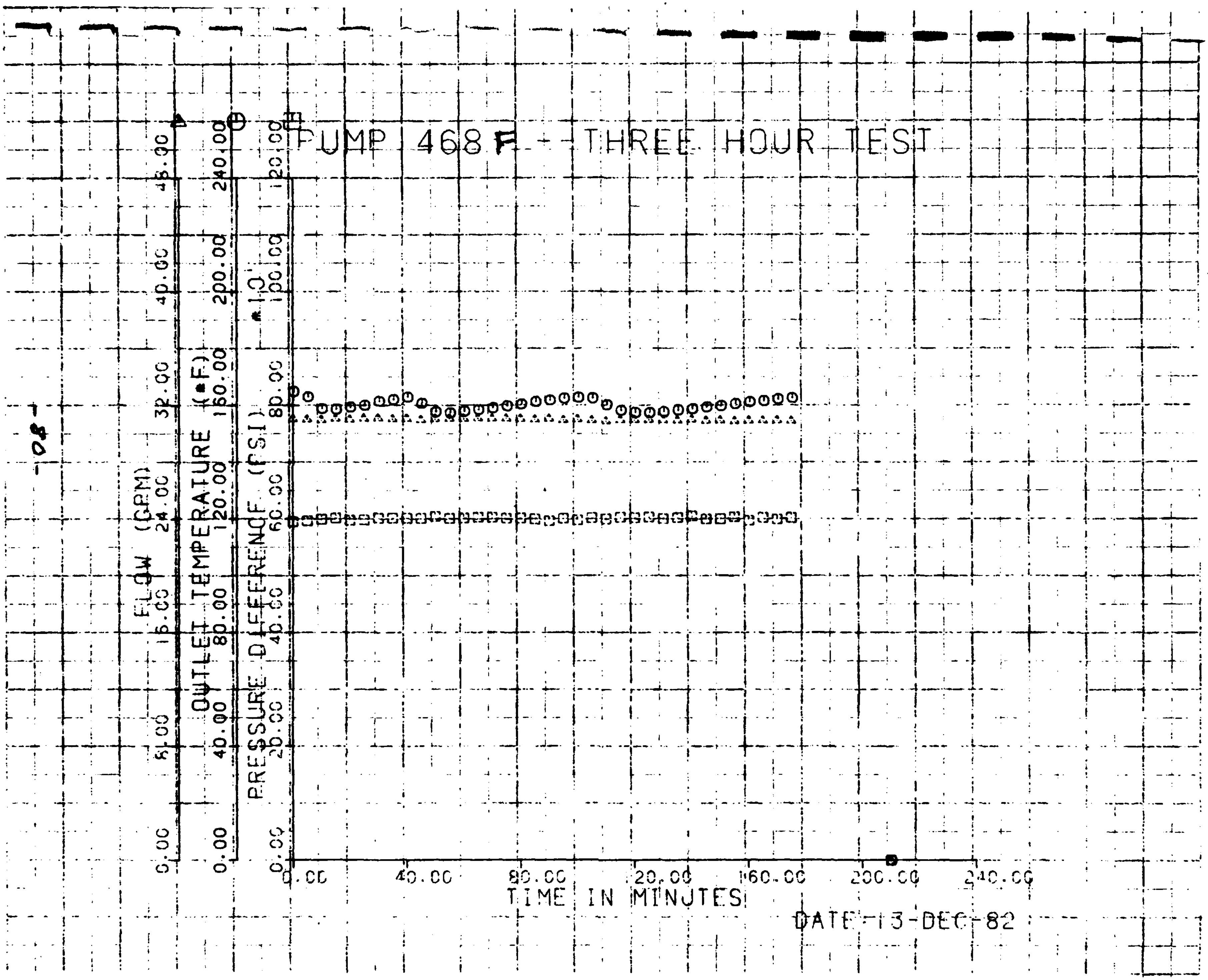
THE STANDARD DEVIATION OF THE:

MEASURED FLOW IS: .170904 GPM
MEASURED SPEED IS: 5.93671 RPM
MEASURED TORQUE IS: 3.91295 IN-LB
DIFFERENTIAL PRESSURE IS: 5.9736 PSID

THE MAX. OVER ALL EFFICIENCY IS: 76.4468
THE MIN. OVER ALL EFFICIENCY IS: 74.9639
THE AVERAGE OVER ALL EFFICIENCY IS: 75.759

THE MAX. VOLUMETRIC EFFICIENCY IS: 95.9272
THE MIN. VOLUMETRIC EFFICIENCY IS 95.1443
THE AVERAGE VOLUMETERIC EFFICIENCY IS 95.5695

THE MAX. MECHANICAL EFFICIENCY IS 79.8768
THE MIN. MECHANICAL EFFICIENCY IS 78.4019
THE AVERAGE MECHANICAL EFFICIENCY IS 79.2581



PUMP 468 F - THREE HOUR TEST
FLOW (GPM)
0.00
8.00
16.00
24.00
32.00
40.00
48.00
OUTLET TEMPERATURE (°F)
0.00
40.00
80.00
120.00
160.00
200.00
240.00
PRESSURE DIFFERENCE (PSI) *10'
0.00
20.00
40.00
60.00
80.00
100.00
120.00
TIME IN MINUTES
0.00
40.00
80.00
120.00
160.00
200.00
240.00
DATE 13-DEC-82

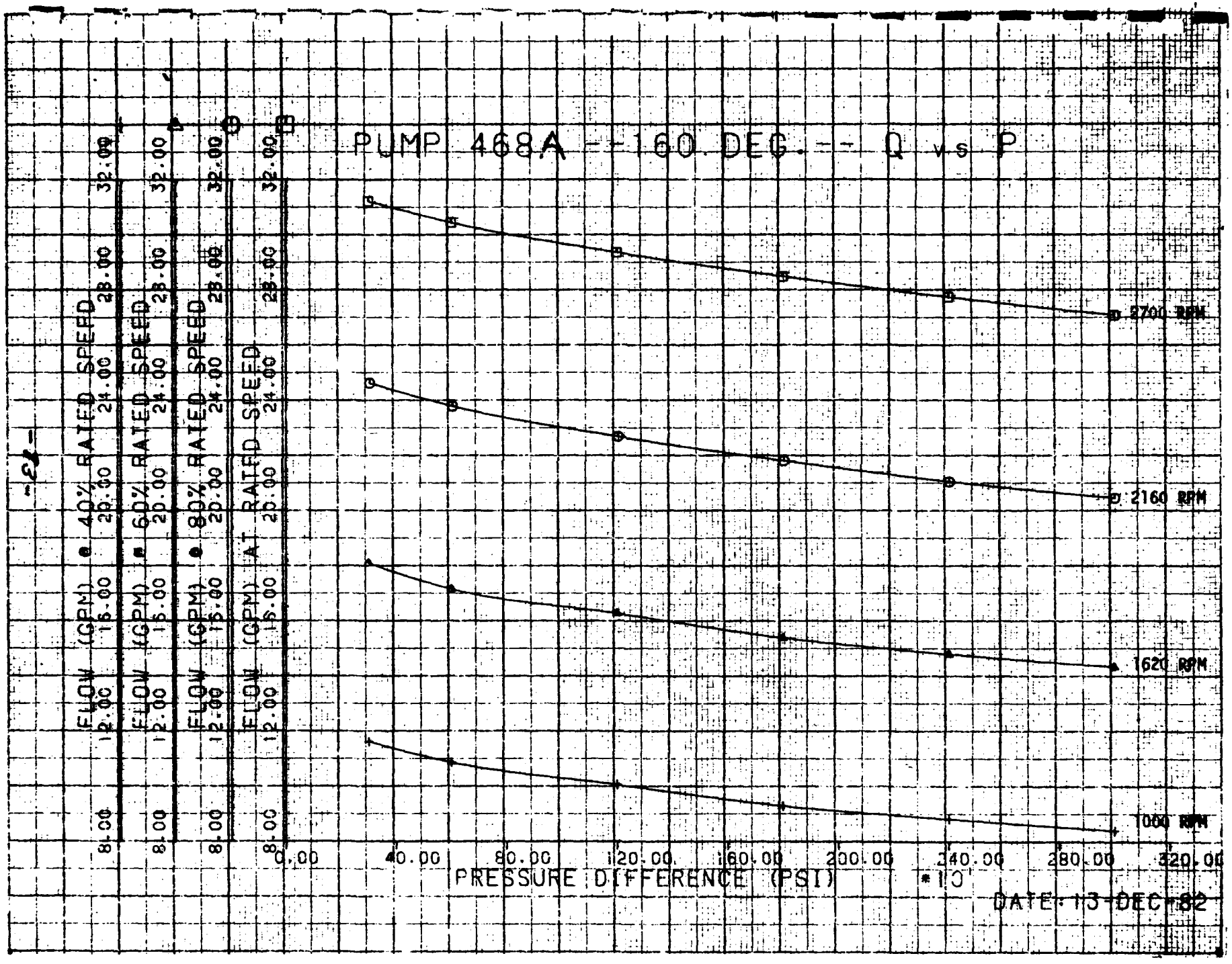
APPENDIX F

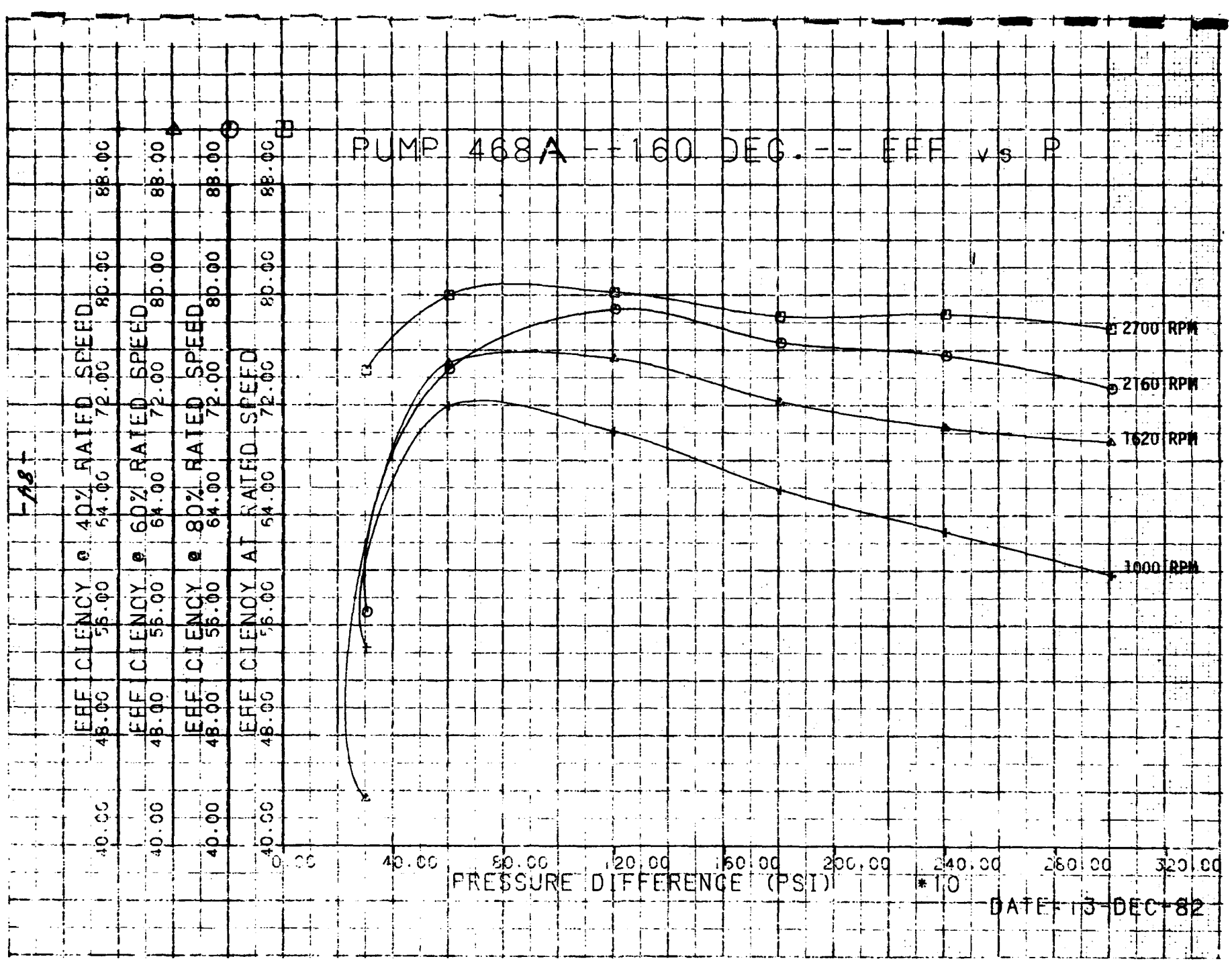
TABULATED AND GRAPHICAL DATA FROM POWER CONVERSION TEST

POWER CONVERSION TEST
PUMP NUMBER M1468A RUN AT 160 DEGREES (F) INLET TEMP.

OUTLET TEMP(F)	TOR. SPEED RPM	ADJ FLOW GPM	TOR PRESS PSID	ADJ TORQ IN-LBS	OUTPUT HP	INPUT HP	OVER ALL EFF(%)	VOL EFF (%)	MECH EFF (%)	SIM DIS in^3/rev
168.48	7700.00	27.89	3000.00	1418.51	47.13	60.77	77.55	86.77	89.91	2.39
166.88	7700.00	27.74	2400.00	1170.38	38.74	49.78	78.08	88.85	88.68	2.37
164.38	7700.00	28.49	1800.00	874.19	29.38	37.45	78.44	91.24	87.54	2.44
160.98	7700.00	29.36	1200.00	580.89	20.71	25.83	80.17	94.80	84.62	2.51
158.98	7700.00	30.45	600.00	305.98	11.18	13.88	79.97	97.59	78.73	2.68
160.68	7700.00	31.77	300.00	183.47	5.86	7.86	74.58	100.00	69.59	2.67
167.38	7100.00	28.46	3000.00	1418.84	35.61	48.63	73.23	81.93	89.89	2.19
166.58	7100.00	21.86	2400.00	1144.28	29.65	39.27	75.61	84.37	89.17	2.25
162.58	7100.00	21.89	1800.00	863.91	22.66	29.61	76.54	87.34	88.58	2.33
162.48	7100.00	22.68	1200.00	598.13	15.97	20.73	78.96	90.89	86.45	2.43
157.58	7100.00	23.79	600.00	313.86	8.81	10.73	74.63	95.25	81.48	2.54
158.28	7100.00	24.63	300.00	181.88	3.55	6.23	56.97	98.63	78.12	2.63
167.68	6500.00	14.36	3000.00	1417.78	25.29	36.44	69.39	76.67	89.96	2.86
166.48	6500.00	14.89	2400.00	1138.36	20.61	29.26	70.42	79.11	89.63	2.11
163.18	6500.00	15.41	1800.00	858.23	15.97	22.89	72.31	82.25	88.86	2.78
158.58	6500.00	16.38	1200.00	585.18	11.35	15.84	75.42	87.81	87.18	2.39
158.78	6500.00	17.18	600.00	300.91	5.85	7.79	75.12	91.78	84.21	2.45
156.18	6500.00	18.11	300.00	179.18	2.88	4.68	43.45	96.68	71.21	2.58
172.18	5900.00	8.48	3000.00	1432.87	14.64	24.54	59.67	67.26	88.86	1.88
169.88	5900.00	8.81	2400.00	1145.24	12.32	19.63	62.78	70.58	88.88	1.89
164.38	5900.00	9.28	1800.00	858.72	9.69	14.72	65.83	74.31	88.11	1.98
158.48	5900.00	10.05	1200.00	588.17	6.97	9.94	70.07	80.47	87.53	2.15
158.48	5900.00	10.86	600.00	294.81	3.63	5.85	71.97	86.55	86.59	2.39
168.88	5900.00	11.63	300.00	154.43	1.44	2.65	54.38	92.93	80.58	2.48
169.38	5300.00	4.38	3000.00	1445.84	7.44	19.84	39.88	44.78	88.21	1.28
169.28	5300.00	4.79	2400.00	1150.77	6.64	15.17	43.76	49.93	88.56	1.33
171.78	5300.00	5.53	1800.00	868.56	5.74	11.45	50.11	57.66	88.88	1.54
163.48	5300.00	6.56	1200.00	583.18	4.46	7.68	58.11	68.39	87.49	1.89
158.78	5300.00	7.65	600.00	292.75	2.53	3.86	65.78	79.74	87.13	2.13
156.88	5300.00	8.56	300.00	158.18	1.43	1.98	72.18	89.15	84.97	2.38

THE MAX. OVER ALL EFFICIENCY IS: 80.1677
THE MIN. OVER ALL EFFICIENCY IS: 39.0811
THE MAX. SIMPLE DISPLACEMENT IS: 2.67118

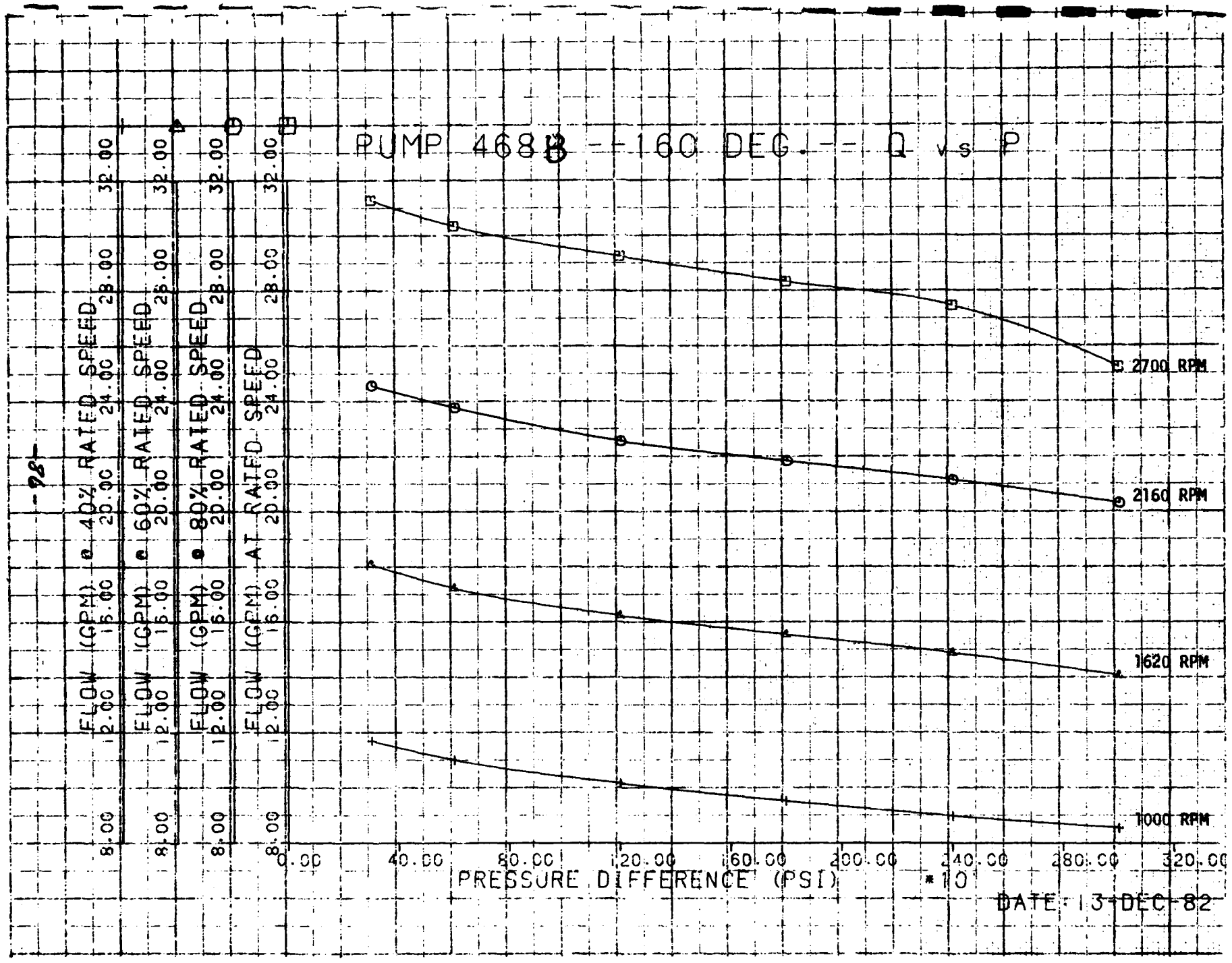

PUMP 468A -- 160 DEG. -- Q vs P
FLOW (GPM) ● 40% RATED SPEED
FLOW (GPM) ■ 60% RATED SPEED
FLOW (GPM) ◆ 80% RATED SPEED
FLOW (GPM) AT RATED SPEED
32.00
28.00
24.00
20.00
16.00
12.00
8.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00
280.00
320.00
PRESSURE DIFFERENCE (PSI)
*10
2700 RPM
2160 RPM
1620 RPM
1080 RPM
DATE: 13-DEC-82
-23-

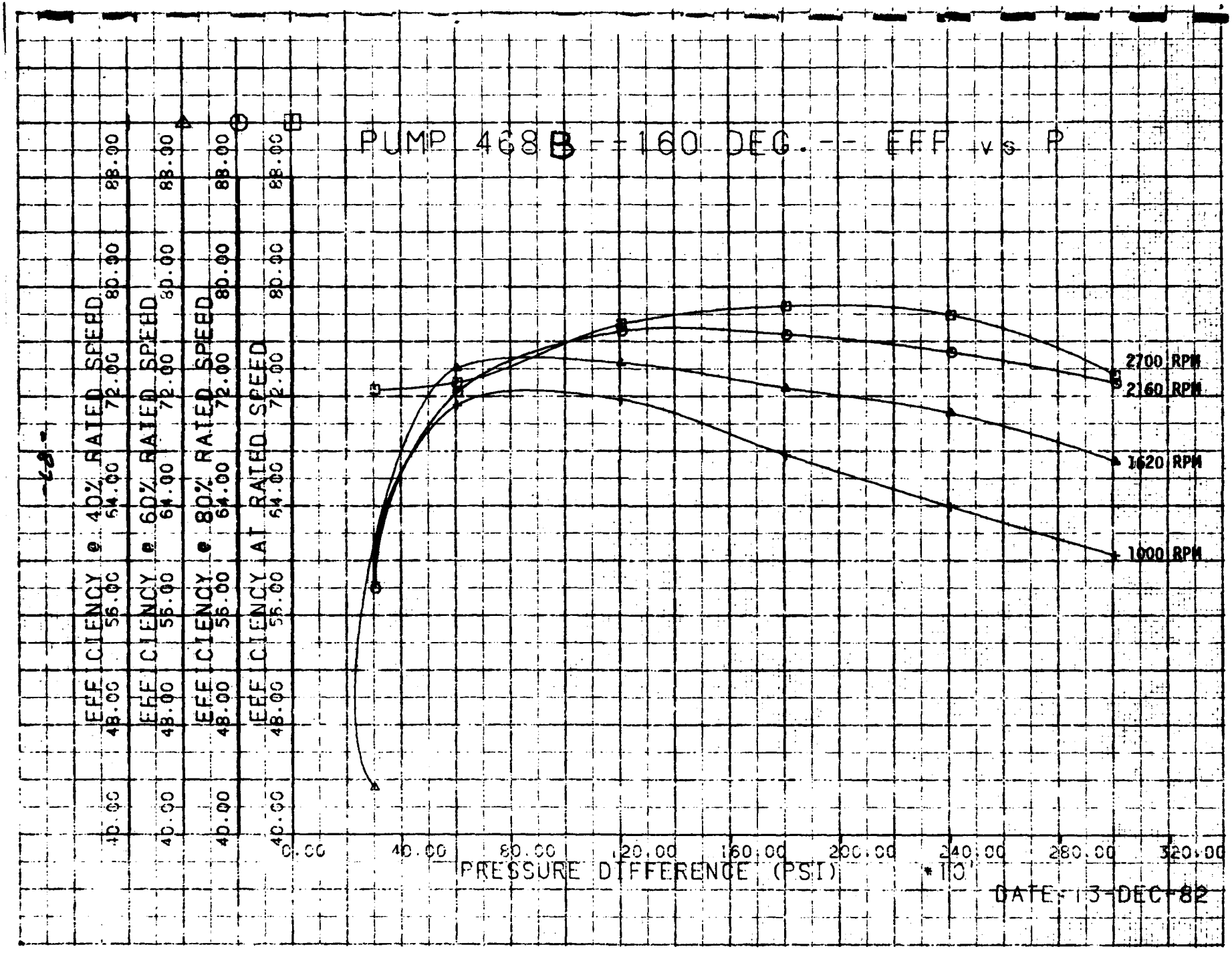

PUMP 468A -- 160 DEG. -- EFF vs P
EFFICIENCY @ 40% RATED SPEED
EFFICIENCY @ 60% RATED SPEED
EFFICIENCY @ 80% RATED SPEED
EFFICIENCY AT RATED SPEED
88.00
80.00
72.00
64.00
56.00
48.00
40.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00
280.00
320.00
2700 RPM
2160 RPM
1620 RPM
1000 RPM
PRESSURE DIFFERENCE (PSI)
*10
DATE 13 DEC 82

POWER CONVERSION TEST
PUMP NUMBER M1468B RUN AT 160 DEGREES (F) INLET TEMP.

OUTLET TEMP(F)	TOR. SPEED RPM	ADJ FLOW GPM	TOR PRESS PSID	ADJ TORQ IN-LBS	OUTPUT HP	INPUT HP	OVER ALL EFF(%)	VOL EFF (%)	MECH EFF (%)	SIM DIS in^3/rev
172.40	2700.00	25.24	3000.00	1418.64	44.43	60.43	73.50	98.68	98.59	2.16
165.00	2700.00	27.47	2400.00	1151.71	38.44	49.34	77.91	97.81	98.77	2.35
164.60	2700.00	28.33	1800.00	870.51	29.51	37.55	78.58	98.55	97.48	2.42
160.30	2700.00	29.25	1200.00	605.47	20.83	25.94	77.24	93.51	84.43	2.58
158.20	2700.00	30.35	600.00	338.65	10.34	14.17	72.99	97.81	77.38	2.68
160.70	2700.00	31.20	300.00	168.66	5.86	8.08	72.46	100.00	67.73	2.68
170.70	2100.00	20.32	3000.00	1419.25	35.48	48.64	72.95	81.19	98.84	2.17
167.50	2100.00	21.16	2400.00	1143.34	29.47	39.19	75.20	84.54	89.42	2.26
164.50	2100.00	21.84	1800.00	868.54	22.77	29.77	76.51	87.27	88.28	2.34
161.30	2100.00	22.57	1200.00	595.57	15.61	20.34	76.75	90.17	86.17	2.41
158.40	2100.00	23.28	600.00	318.78	7.98	10.93	72.31	95.00	88.18	2.54
160.60	2100.00	24.57	300.00	183.41	3.64	6.29	57.98	98.19	69.68	2.63
173.20	1500.00	14.18	3000.00	1425.64	24.65	36.65	67.27	75.11	89.64	2.81
167.60	1500.00	14.91	2400.00	1144.17	20.83	29.41	70.81	79.43	89.35	2.13
164.70	1500.00	15.57	1800.00	864.54	16.14	22.22	72.65	87.95	88.69	2.22
161.60	1500.00	16.27	1200.00	588.44	11.22	15.87	74.46	86.66	87.16	2.32
158.40	1500.00	17.25	600.00	305.27	5.82	7.85	74.11	91.91	83.72	2.46
156.10	1500.00	18.11	300.00	179.10	2.98	4.68	63.45	96.58	71.35	2.58
175.60	1000.00	8.56	3000.00	1447.84	14.93	24.73	60.37	68.43	88.57	1.83
169.30	1000.00	8.98	2400.00	1158.63	12.68	19.72	63.97	71.78	88.85	1.99
164.50	1000.00	9.57	1800.00	863.00	10.81	14.79	67.78	76.85	88.85	2.04
160.00	1000.00	10.15	1200.00	577.21	7.89	9.89	71.73	81.15	88.56	2.17
158.20	1000.00	11.00	600.00	297.67	3.64	5.18	71.35	87.89	85.86	2.35
160.50	1000.00	11.69	300.00	150.34	1.59	2.73	58.39	93.39	68.28	2.58
193.60	650.00	4.21	3000.00	1474.77	7.39	19.42	37.78	43.74	86.65	1.17
182.40	650.00	4.94	2400.00	1163.29	6.89	15.39	44.50	51.39	87.88	1.38
173.40	650.00	5.63	1800.00	881.77	5.88	11.61	50.65	58.56	86.96	1.57
164.00	650.00	6.56	1200.00	585.71	4.55	7.71	58.84	68.24	87.27	1.83
158.90	650.00	7.79	600.00	294.55	2.71	3.88	69.76	81.83	86.77	2.17
156.00	650.00	8.56	300.00	158.18	1.43	1.98	72.18	88.98	85.14	2.38

THE MAX. OVER ALL EFFICIENCY IS: 78.5804
THE MIN. OVER ALL EFFICIENCY IS: 37.6988
THE MAX. SIMPLE DISPLACEMENT IS: 2.67643

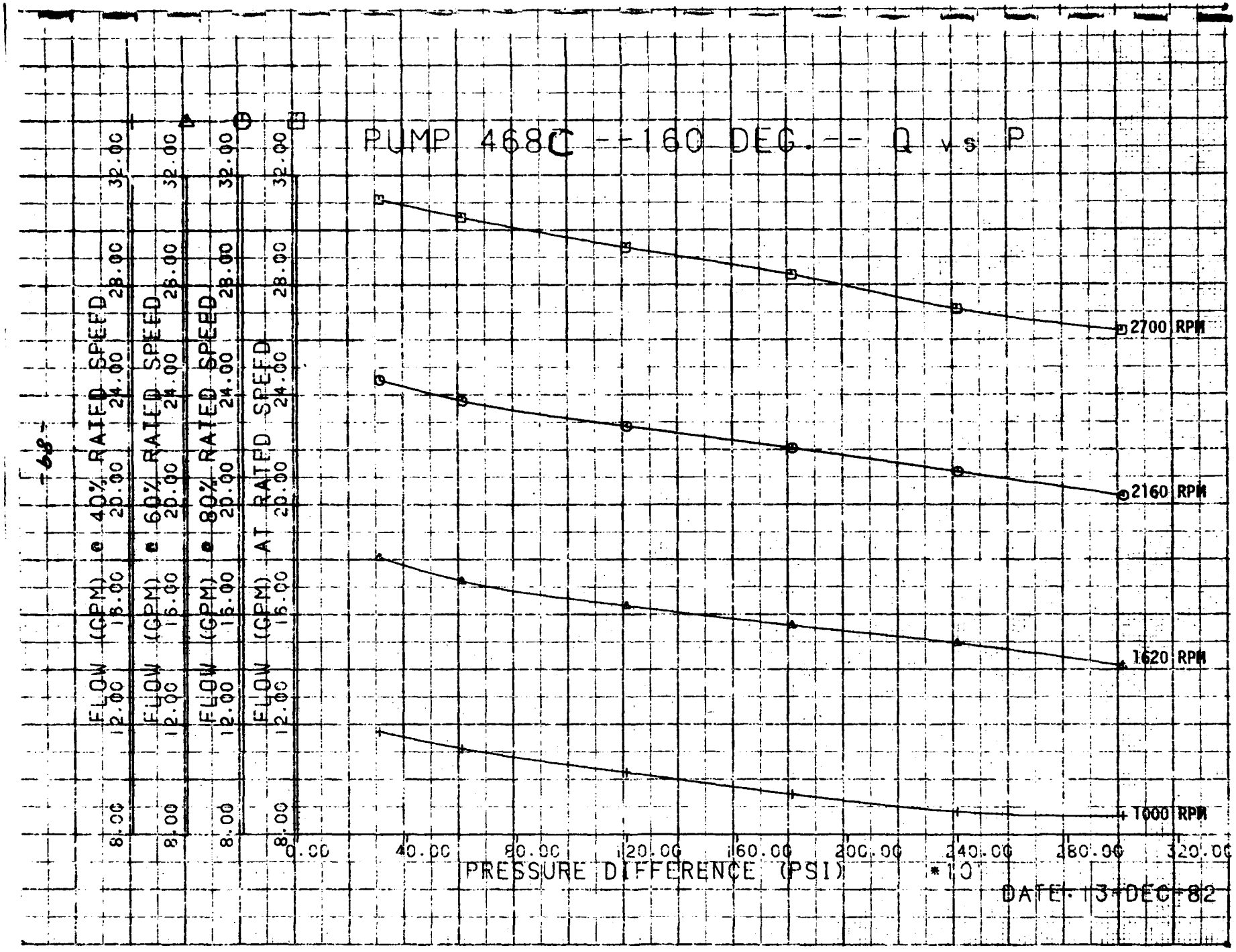

PUMP 4688 --160 DEG.-- Q vs P
FLOW (GPM) @ 40% RATED SPEED
FLOW (GPM) @ 60% RATED SPEED
FLOW (GPM) @ 80% RATED SPEED
FLOW (GPM) AT RATED SPEED
2.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
2700 RPM
2160 RPM
1620 RPM
1000 RPM
0.00
40.00
80.00
120.00
160.00
200.00
240.00
280.00
320.00
PRESSURE DIFFERENCE (PSI)
*10
DATE: 13-DEC-82

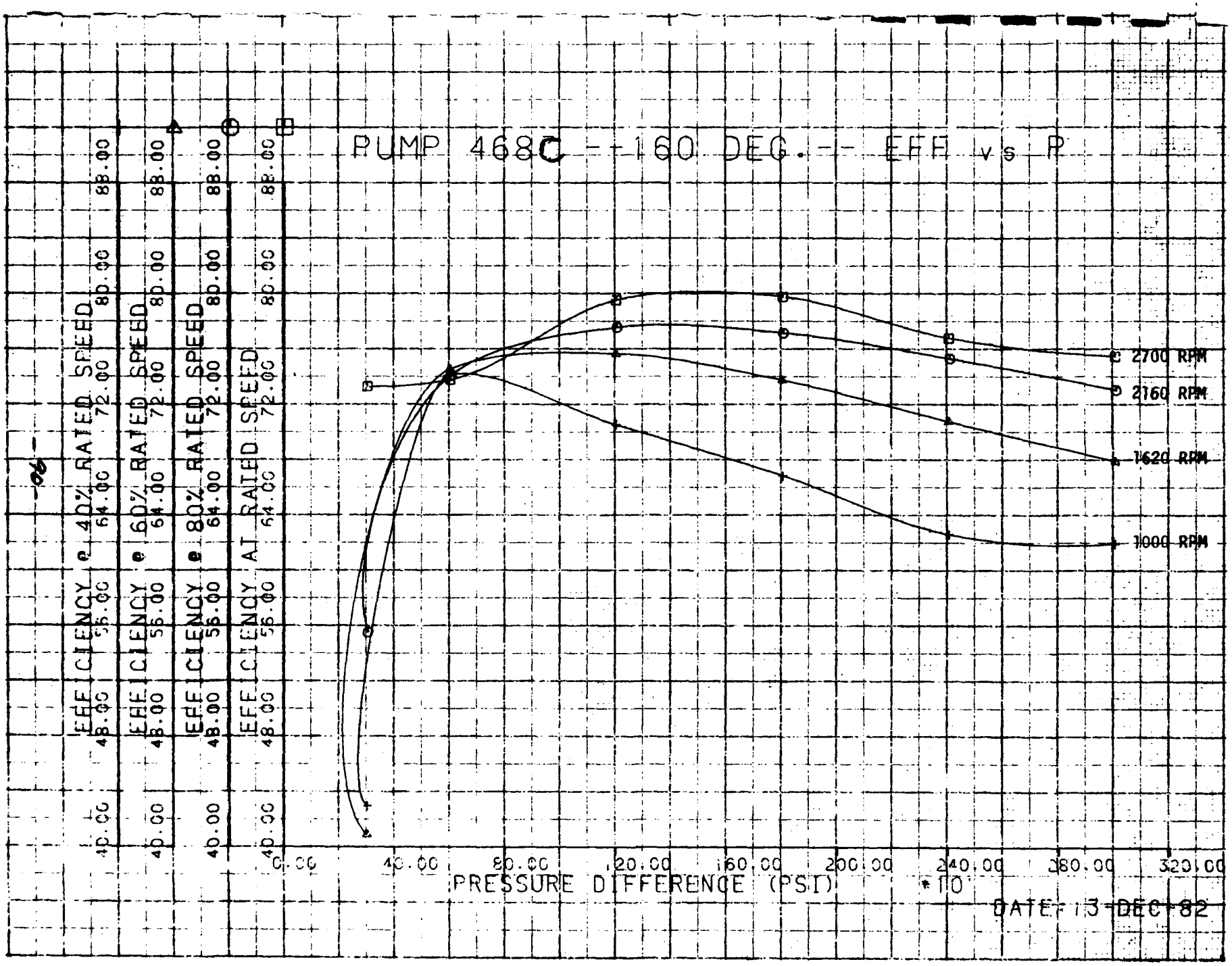

PUMP 468B - -160 DEG. - - EFF vs P
EFFICIENCY @ 40% RATED SPEED
EFFICIENCY @ 60% RATED SPEED
EFFICIENCY @ 80% RATED SPEED
EFFICIENCY AT RATED SPEED
40.00
48.00
56.00
64.00
72.00
80.00
88.00
2700 RPM
2160 RPM
1620 RPM
1000 RPM
0.00
40.00
80.00
120.00
160.00
200.00
240.00
280.00
320.00
PRESSURE DIFFERENCE (PSI) *10
DATE: 13-DEC-82

POWER CONVERSION TEST
PUMP NUMBER M1468[illegible] RUN AT 160 DEGREES (F) INLET TEMP.

OUTLET TEMP(F)	TOR. SPEED RPM	ADJ FLOW GPM	TOR PRESS PSID	ADJ TORQ IN-LBS	OUTPUT HP	INPUT HP	OVER ALL EFF(%)	VOL EFF (%)	MECH EFF (%)	SIM DIS in^3/rev
172.30	2700.00	20.33	3000.00	1425.69	40.89	61.00	75.46	84.60	89.16	2.75
168.70	2700.00	22.12	2400.00	1144.76	32.66	49.84	76.79	87.14	88.83	2.32
163.00	2700.00	20.37	1800.00	877.20	29.00	37.37	79.76	91.16	87.45	2.43
162.00	2700.00	20.36	1200.00	600.07	20.47	25.74	79.59	94.35	84.69	2.51
158.10	2700.00	30.46	600.00	330.35	10.47	14.20	73.77	97.00	76.73	2.61
160.20	2700.00	31.12	300.00	168.13	5.91	8.06	73.28	100.00	67.57	2.66
170.50	2100.00	20.32	3000.00	1427.00	35.69	48.76	73.84	81.61	89.34	2.17
166.50	2100.00	21.20	2400.00	1145.77	29.58	39.27	75.32	85.14	88.76	2.27
163.60	2100.00	22.06	1800.00	869.60	23.00	29.90	77.17	88.60	87.71	2.36
160.20	2100.00	22.85	1200.00	585.19	15.82	20.46	77.57	91.00	85.43	2.44
157.60	2100.00	23.70	600.00	318.37	8.69	10.91	74.11	95.54	79.86	2.54
156.00	2100.00	24.55	300.00	167.57	3.57	6.43	55.59	98.01	67.77	2.63
172.90	1600.00	14.15	3000.00	1419.95	24.00	36.50	67.94	75.00	89.59	2.60
168.50	1600.00	14.98	2400.00	1142.65	20.00	29.37	70.83	80.22	88.00	2.14
165.50	1600.00	15.60	1800.00	861.22	16.34	22.14	73.81	83.64	88.56	2.23
161.00	1600.00	16.33	1200.00	583.20	11.35	14.99	75.70	87.47	87.17	2.33
161.40	1600.00	17.24	600.00	306.14	5.87	7.87	74.58	92.33	83.84	2.46
155.90	1600.00	18.00	300.00	160.76	1.92	4.70	40.95	96.91	69.56	2.58
173.40	1000.00	8.67	3000.00	1432.41	15.20	24.55	61.94	69.65	88.74	1.65
169.70	1000.00	8.82	2400.00	1149.93	12.34	19.71	62.60	78.87	88.44	1.89
162.90	1000.00	9.45	1800.00	864.47	9.90	14.81	66.84	75.88	88.23	2.00
159.90	1000.00	10.24	1200.00	588.62	7.02	9.95	70.50	87.28	87.57	2.19
156.60	1000.00	11.11	600.00	297.13	3.78	5.09	74.18	89.25	85.56	2.38
154.10	1000.00	11.73	300.00	168.81	1.24	2.89	42.96	94.23	75.38	2.51
169.90	800.00	4.48	3000.00	1440.65	7.87	19.85	41.32	46.79	87.87	1.25
173.40	800.00	5.32	2400.00	1151.49	7.41	15.16	48.84	55.64	88.32	1.48
167.40	800.00	6.00	1800.00	865.48	6.38	11.48	55.77	63.54	88.13	1.69
162.20	800.00	6.86	1200.00	578.13	4.77	7.61	62.62	71.67	87.95	1.91
156.50	800.00	7.92	600.00	291.36	2.77	3.84	70.91	80.83	87.76	2.21
160.20	800.00	8.77	300.00	158.12	0.94	2.08	45.00	91.21	88.39	2.43

THE MAX. OVER ALL EFFICIENCY IS: 79.7636
THE MIN. OVER ALL EFFICIENCY IS: 40.9456
THE MAX. SIMPLE DISPLACEMENT IS: 2.66235


PUMP 468C --160 DEG.-- Q vs P
FLOW (GPM) @ 40% RATED SPEED
FLOW (GPM) @ 60% RATED SPEED
FLOW (GPM) @ 80% RATED SPEED
FLOW (GPM) AT RATED SPEED
8.00
12.00
16.00
20.00
24.00
28.00
32.00
2700 RPM
2160 RPM
1620 RPM
1000 RPM
0.00
40.00
80.00
120.00
160.00
200.00
240.00
280.00
320.00
PRESSURE DIFFERENCE (PSI)
*10
DATE: 13-DEC-82

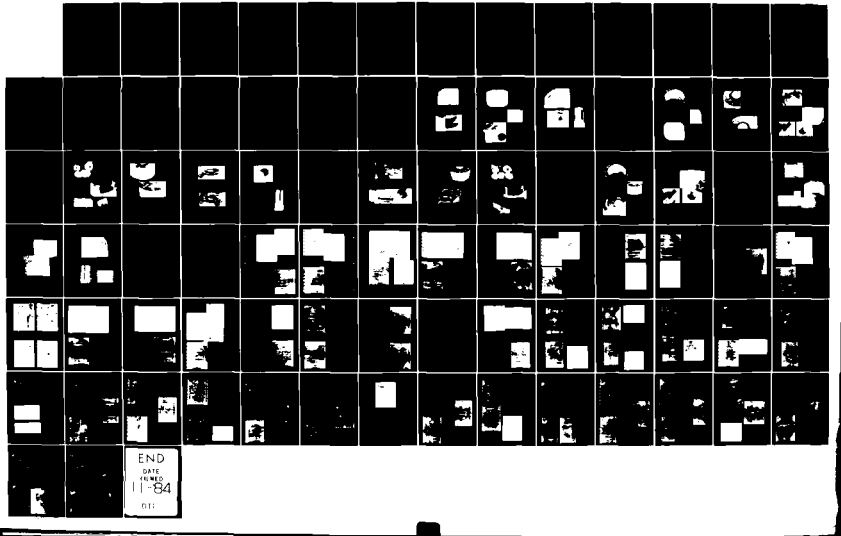

PUMP 468C -+160 DEG.-- EFF vs P
EFFICIENCY @ 40% RATED SPEED
EFFICIENCY @ 60% RATED SPEED
EFFICIENCY @ 80% RATED SPEED
EFFICIENCY AT RATED SPEED
40.00
48.00
56.00
64.00
72.00
80.00
88.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00
280.00
320.00
PRESSURE DIFFERENCE (PSI) * 10
2700 RPM
2160 RPM
1620 RPM
1000 RPM
DATE: 13-DEC-82

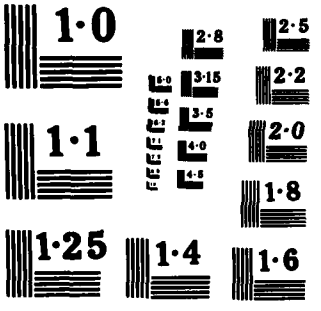
AD A146 023 A STUDY OF WEAR CHARACTERISTICS DUE TO PRESSURE FOR HYDRAULIC FIXED DISPL (U) MILWAUKEE SCHOOL OF ENGINEERING WI FLUID POWER INST OCT 83 P/N 5046A

2/2

UNCLASSIFIED DAAK70 81 C 0002

F/G 13/11 NL




1·0
1·1
1·25
2·8
3·15
3·5
4·0
4·5
2·5
2·2
2·0
1·8
1·4
1·6

APPENDIX G

Tabulated Gravimetric Data

GRAVIMETRIC ANALYSIS

The gravimetric analysis was done to determine the mass of the solid contaminants (larger than 0.45 micrometer) in selected oil samples from the test pumps. Samples with relatively high particle count results were chosen. Results are reported in milligrams of contaminant per liter of sample oil.

Millipore filter patches (size 0.45 micron) were used to collect the solid contaminants. An analytical balance with readability of 0.1 milligram was used to make mass determinations. A millipore filter patch apparatus cleaned in accordance with NFPA/T2.9.2M-1972, ANSI/B93.20M-1972 (R1980), ISO3722 methods was used to filter the oil samples through the patches. Filtered freon was used to remove the oil from the patches so that only the solid contaminant remained on the patch.

The gravimetric level of the samples should correspond to the particle count results.

GRAVIMETRIC FILTER PATCH ANALYSIS

The gravimetric filter patch data from pumps 468C, 468D and 468E has been deleted from this report due to reasons listed below. After a couple of filter patches were analyzed from each pump, the weight of contaminant was found to be very low, in the range of .2 to .3 mg of contaminant. The range of contaminant weight seem to correlate with the low particle counts on the samples from pumps 468C, 468D and 468E. This also correlated with the ferrogram results. The ferrogram results were not recorded in this report for the same above mentioned reason. Therefore, pages 94-97 were omitted from the report.

APPENDIX H

Tabulated X-Ray Emmission Data

Pages 94 thru 97 were intentionally left blank per Mr. Son Nguyen, ABRDC

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST NON-DESTRUCTIVE: X-RAY EMMISSION
Analysis on Oil Samples

DESCRIPTION Break-In Test of Pump

COMMENTS 10 ua, 25kv, 1005 Run Time.
Samples x-rayed under vacuum (50 microns)

PROJECT NO. Pump #468F
DATE Feb. 3-4, 1983
TECHNICIAN B. Batley

INSTRUMENTATION
Ortec Tefa
Model 6110

Sample #	Al	Si	S	Ca	Fe	Cu	Zn	Pb	
1	168	236	4091	1917	870	1141	6704	1057	
2	171	209	4582	2076	790	1052	5744	903	
3	172	228	5015	2217	855	1079	8212	966	
4	188	267	5081	2353	925	1168	8260	945	
A 5	185	282	4981	2367	992	1237	9133	1013	
6	165	214	4800	2201	719	847	5462	516	
7	191	247	5082	2292	470	1250	9385	1082	
8	201	211	4755	2332	899	1296	9408	1100	
9	194	248	5009	2331	968	1251	9159	1049	
10	181	249	5143	2513	940	1425	10858	1325	
11	196	242	4997	2305	956	1109	8026	938	
12	172	246	4315	2159	956	1227	9855	1180	
13	181	249	4687	2311	853	952	6777	720	
14	189	252	4817	1848	927	1154	8796	1097	
15	201	228	4881	2248	869	1206	9733	1040	
16	164	248	4844	2367	842	1135	8787	991	
17	172	244	4866	2316	841	1078	7764	858	
18	173	244	4812	2322	914	1203	9332	1133	
19	176	259	5048	2417	957	1120	8635	999	
20	176	230	4714	2193	885	1138	8057	914	
21	160	238	4760	2388	917	1106	8444	913	

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST NONDESTRUCTIVE: X-RAY EMMISION ANALYSIS OF OIL SAMPLES

FILTER PATCHES

DESCRIPTION Data taken is count rate corresponding to elements energy level.

Anode Status: 20 μA; 35 KV

COMMENTS 200 sec. run time

50 micron vacuum

PROJECT NO. Pump#468F 50468

DATE 4-15-83

TECHNICIAN B. BATLEY

INSTRUMENTATION ORTEC TEFA MODEL 6110

Sample#	Cl	Cr	S	Ca	Fe	Cu	Zn	Pb (Lα)	
48,49	4536		10820	3489	1290		5025		Orig. Peak
	1394		1569	394	946		953		Left Bkgnd.
	700		1394	602	789		734		Rt. Bkgnd.
*	3489		9338	2986	422		4181		True Peak
50,51	4543		11015	3838	1079		4966		
	1436		1676	390	820		961		
	421		1436	593	869		804		
*	3614		9459	3346	234		4083		True Peak
52,53	4287	1043	9871	3550	2210		5321		
	1263	581	1425	349	948		1092		
	577	768	1263	630	937		761		
*	3367	368	8527	3060	1267		4394		True Peak
54,55	4403		10785	3382	1005		4714		
	1345		1556	431	894		1037		
	571		1345	610	912		682		
*	3445		9334	2861	102		3854		True Peak
56,57	4668	922	11975	4014	1130		5673		
	1511	691	1709	406	1018		1105		
	686	848	1511	613	989		880		
*	3569	152	10365	3504	126		4680		True Peak
58,59	4161		9424	3118	933		4390		
	1243		1404	374	786		990		
	507		1243	526	832		702		
*	3286		8100	2668	124		3544		True Peak

FLUID POWER INSTITUTE
MILWAUKEE SCHOOL OF ENGINEERING

TEST NONDESTRUCTIVE: X-RAY EMMISSION ANALYSIS OF OIL SAMPLES

FILTER PATCHES

DESCRIPTION Data taken is count rate corresponding to elements energy level

Anode States; 20ua; 35kv

COMMENTS 200 sec. run time

50 micron vacuum

PROJECT NO. PUMP #468F

DATE 4/15/83

TECHNICIAN B. BATLEY

INSTRUMENTATION

ORTEC TEFA

MODEL 6110

Sample #	Cl	Si	S	Ca	Fe	Cu	Zn	Pb (Lα)	
60,61	4140		10316	3314	989		4978		Orig. Peak
	1311		1510	405	927		999		Lft. Bkgnd.
	517		1311	531	847		704		Rt. Bkgnd.
*	3226		8905	2846	102		4126		True Peak
62,63	4259		9646	3135	897		4072		
	1238		1392	428	816		891		
	434		1238	639	748		765		
*	3423		8331	2601	115		3244		True Peak
64,65	4256		10217	2208			4916		
	1342		1502	383			1002		
	469		1342	611			666		
*	3350		8795	2811			4082		True Peak
66,67	4082		10315	3242	946		4739		
	1288		1526	380	792		925		
	459		1288	588	765		651		
*	3208		8908	2758	167		3951		True Peak
68,69	4380		10545	3567	1076		4994		
	1338		1548	396	871		991		
	452		1338	606	866		772		
*	3485		9102	3066	207		4112		True Peak
70,71	4355		8549	2895			4282		
	1282		1298	316			1079		
	596		1282	533			687		
*	3416		7259	2470			3399		True Peak

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MILWAUKEE SCHOOL OF ENGINEERING

TEST NONDESTRUCTIVE: X-RAY EMMISSION ANALYSIS OF OIL SAMPLES FILTER PATCHES

PROJECT NO. PUMP #468F

DATE 4/18/83

TECHNICIAN B. BATLEY

DESCRIPTION Data taken is count rate corresponding to elements energy level

COMMENTS Anode Status; 10ua; 30kv
50 micron vacuum
200 second run time

INSTRUMENTATION
ORTEC TEFA
MODEL 6110

Sample #	Cl	Si	S	Ca	Fe	Cu	Zn	Pb (Lα)	
74,75	2781		5763	1884			2367		Orig. Peak
	1388		1196	342			610		Lft. Bkgnd.
	524		1388	450			443		True Peak
*	1825		4471	1488			1840		
78,79	2790		6255	1945			2486		
	1370		1537	379			652		
	727		1370	500			486		
*	1741		4801	1505			1917		True Peak
78,79	2812		5529	1603	603		1846		
(2)	1213		1310	287	487		550		
	344		1213	453	485		495		
*	2033		4267	1233	117		1323		True Peak
80,81	2553		4741	1603	581		2180		
	1156		1060	265	535		635		
	312		1156	424	538		437		
*	1819		3633	1258	44		1644		True Peak
82,83	2639	5814	1760			2364			
	1244		1280	352			671		
	278		1244	444			466		
*	1878		4552	1362			1795		True Peak

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MILWAUKEE SCHOOL OF ENGINEERING

TEST NONDESTRUCTIVE: X-RAY EMMISSION ANALYSIS OF OIL SAMPLES FILTER PATCHES

PROJECT NO. PUMP #468F

DATE 4/18/83

TECHNICIAN B. BATLEY

DESCRIPTION Data taken is count rate corresponding to elements energy level.

COMMENTS Anode Status: 10ua; 30kv
50 micron vacuum
200 second run time

INSTRUMENTATION
ORTEC TEFA
MODEL 6110

Sample #	Cl	Si	S	Ca	Fe	Cu	Zn	Pb(Lα)	
84,85	2413		4583	1489			1979		Orig. Peak
	1066		1002	281			531		Lft. Bkgnd.
	342		1066	381			382		Rt. Bkgnd.
	1709		3549	1158			1522		True Peak
88,89	2540		5127	1682			2219		
	1127		1111	282			439		
	388		1127	437			688		
	1790		4008	1322			1655		True Peak

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MILWAUKEE SCHOOL OF ENGINEERING

TEST NONDESTRUCTIVE: X-RAY EMMISSION ANALYSIS OF OIL SAMPLES FILTER PATCHES

PROJECT NO. Pump #468F

DATE 4-14-83

TECHNICIAN B. Batley

DESCRIPTION Data taken is count rate corresponding to elements energy level.

COMMENTS Anode Status: 20ua; 35kv
50 micron vacuum
200 sec. run time

INSTRUMENTATION
ORTEC TEFA
MODEL 6110

*True Peak Coloum

Sample #	Cl	Si	S	Ca	Fe	Cu	Zn	Pb(Lα)	
88,89	4589		9037	2929	931	912	4542		Orig. Peak
	1176		1344	360	803	749	1045		Left Bkgnd.
	441		1176	589	827	872	712		Right Bkgnd.
*	3780		7777	2454	116	101	3663		True Peak
90,91	4648		9706	2863			3692		
	1338		1468	391			971		
	439		1338	596			721		
*	3759		8303	2369			2846		True Peak
92,93	4666		8515	2795			3968		
	1246		1317	376			919		
	517		1246	561			595		
*	3784		7233	2326			3211		True Peak
94,95	4353		8392	2726	888	905	4095		
	1160		1224	339	794	770	910		
	373		1160	513	770	811	713		
*	3586		7200	2300	106	114	3283		True Peak
96,97	4006		8332	2668	822		3481		
	1226		1266	348	746		870		
	394		1226	523	694		548		
*	3196		7086	2232	102		2574		True Peak
98,99	4454		8734	2812			4042		
	1215		1389	362			896		
	351		1215	519			633		
*	3671		7432	2371			3277		True Peak

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MILWAUKEE SCHOOL OF ENGINEERING

TEST NONDESTRUCTIVE: X-RAY EMMISSION ANALYSIS OF OIL SAMPLES FILTER PATCHES

PROJECT NO. Pump #468F

DATE 4-8-83

TECHNICIAN B. Batley

DESCRIPTION Data taken is count rate corresponding to elements energy level.

COMMENTS Anode Status: 20ua; 35kv
50 micron vacuum
200 sec. run time

INSTRUMENTATION
ORTEC TEFA
MODEL 6110

Sample #	Cl	Si	S	Ca	Fe	Cu	Zn	Pb(Lα)	
100,101	2139		4278	1381	529		2224		Orig. Peak
	649		641	181	419		509		Left Bkgnd.
	253		649	266	446		325		Right Bkgnd.
*	1688		3633	1158	96		1807		True Peak
102,103	2312		5005	1792	598		3059		
	651		675	334	498		590		
	149		651	306	523		430		
*	1912		4342	1472	87		2549		True Peak
104,105	2114		4788	1478			2030		
	637		709	139			431		
	179		637	249			309		
*	1706		4115	1248			1660		True Peak
106,107	2205		4724	1556			2335		
	676		711	198			500		
	187		676	278			350		
*	1773		4030	1318			1910		True Peak
108,109	2183		5242	1474	2129		2231		
	667		762	181	428		487		
	206		667	261	440		342		
*	1746		4527	1253	1695		1816		True Peak
				-105-					

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TEST NONDESTRUCTIVE: X-RAY EMMISSION ANALYSIS OF OIL SAMPLES FILTER PATCHES

PROJECT NO. Pump #468F

DATE 4-6-83

TECHNICIAN B. Batley

DESCRIPTION Data taken is count rate corresponding to elements energy level.

COMMENTS Anode Status: 20ua; 35kv
50 micron vacuum
100 sec. run time

INSTRUMENTATION
ORTEC TEFA
MODEL 6110

Sample #	Cl	Si	S	Ca	Fe	Cu	Zn	Pb(Lα)	
100,101	1592			878			2522		Orig. Peak
	174			148			1844		Left Bkgnd.
	150			300			1523		Right Bkgnd.
*	1430			654			838.5		True Peak
102,103	1571			810			2575		Orig. Peak
	162			170			1838		Left Bkgnd.
	137			234			1497		Right Bkgnd.
*	1421.5			608			907.5		True Peak
104,105	1560			854			2366		Orig. Peak
	151			138			1850		Left Bkgnd.
	199			267			1471		Right Bkgnd.
*	1385			651.5			705.5		True Peak
106,107	1536			899			2637		Orig. Peak
	150			199			2007		Left Bkgnd.
	149			273			1514		Right Bkgnd.
*	1385.5			663			876.5		True Peak
108,109	1531			861	1251		2556		Orig. Peak
	152			144	1020		1901		Left Bkgnd.
	157			246	1159		1597		Right Bkgnd.
*	1376.5			666	161.5		807		True Peak

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MILWAUKEE SCHOOL OF ENGINEERING

TEST NONDESTRUCTIVE: X-RAY EMMISSION ANALYSIS OF OIL SAMPLES FILTER PATCHES

PROJECT NO. Pump #468F

DATE 4-8-83

TECHNICIAN B. Batley

DESCRIPTION Data taken is count rate corresponding to elements energy level.

COMMENTS Anode Status: 20ua; 35kv
50 micron vacuum
200 sec. run time

INSTRUMENTATION
ORTEC TEFA
MODEL 6110

Sample #	Cl	Si	S	Ca	Fe	Cu	Zn	Pb(Lα)	
110,111	2059		4302	1374	3308		2013		Orig. Peak
	594		633	181	398		507		Left Bkgnd.
	216		594	261	400		343		Right Bkgnd.
*	1654		3688	1153	2909		1588		True Peak
112,113	2290		4966	1538	1106		2128		
	668		697	184	435		518		
	190		669	357	427		309		
*	1861		4283	1267	675		1714		True Peak

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MILWAUKEE SCHOOL OF ENGINEERING

TEST NONDESTRUCTIVE: X-RAY EMMISSION ANALYSIS OF OIL SAMPLES FILTER PATCHES

PROJECT NO. Pump #468F

DATE 4-6-83

TECHNICIAN B. Batley

DESCRIPTION Data taken is count rate corresponding to elements energy level.

COMMENTS Anode Status: 20ua; 35kv
50 micron vacuum
100 sec. run time

INSTRUMENTATION
ORTEC TEFA
MODEL 6110

Sample #	Cl	Si	S	Ca	Fe	Cu	Zn	Pb(Lα)	
110,111	1511			860	1235		2369		Orig. Peak
	167			155	1102		1849		Left Bkgnd.
	174			247	1149		1525		Right Bkgnd.
*	1340.5			659	109.5		682		True Peak
112,113	1628			833	1255		2564		Orig. Peak
	157			163	1102		1860		Left Bkgnd.
	154			259	1210		1628		Right Bkgnd.
*	1472.5			622	99		820		True Peak

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MILWAUKEE SCHOOL OF ENGINEERING

TEST NONDESTRUCTIVE: X-RAY EMMISSION ANALYSIS OF OIL SAMPLES FILTER PATCHES

PROJECT NO. Pump #468F

DATE 4-18-83

TECHNICIAN B. Batley

DESCRIPTION Data taken is count rate corresponding to elements energy level.

COMMENTS Anode Status: 20ua; 35kv
50 micron vacuum
200 sec. run time

INSTRUMENTATION
ORTEC TEFA
MODEL 6110

Sample #	Cl	Si	S	Ca	Fe	Cu	Zn	Pb(Lα)	
114 & 115	2583		5340	1655	981		2218		Orig. Peak
	1162		1127	279	621		573		Left Bkgnd.
	375		1162	419	569		520		Right Bkgnd.
*	1814		4195	1306	386		1671		True Peak
116 & 117	2585		5041	1629	694		2286		
	1117		1086	330	546		583		
	359		1117	410	545		514		
*	1847		3939	1259	103		1737		True Peak
118 & 119	2635		5610	1779	661		2303		
	1138		1170	280	639		552		
	442		1138	461	568		478		
*	1845		4456	1408	57		1788		True Peak
120 & 121	2795		6184	2027	868		2579		
	1338		1417	457	658		646		
	502		1338	509	600		467		
*	1875		4806	1544	239		2022		True Peak
122 & 123	2752		5117	1741	699		2269		
	1141		1035	310	549		577		
	352		1141	481	573		481		
*	2005		4029	1345	138		1740		True Peak

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MILWAUKEE SCHOOL OF ENGINEERING

TEST NONDESTRUCTIVE: X-RAY EMMISSION ANALYSIS OF OIL SAMPLES FILTER PATCHES

PROJECT NO. Pump #468F

DATE 5-6-83

TECHNICIAN B. Batley

DESCRIPTION Data taken is count rate corresponding to elements energy level.

COMMENTS Anode Status: 20ua; 35kv
50 micron vacuum
200 sec. run time

INSTRUMENTATION
ORTEC TEFA
MODEL 6110

Sample #	Cl	Si	S	Ca	Fe	Cu	Zn	Pb(Lα)	
124 & 125	1391		3524	934			958		
124 & 125	1526		3672	1148			1109		
126 & 127	1681		3830	1206	65		1316		
128 & 129	1538		3411	1025	251		1120		
130 & 131	1407		2924	967	252		1014		
132 & 133	1075		2675	723	214		622		
134 & 135	1533		4630	1377	331		1716		
136 & 137	1713		3552	1041	561		1229		
138 & 139	1579		3732	1075	722		1256		
140 & 141	1539		3739	1119	246		1121		
142 & 143	1572		3999	1232	164		1436		
144 & 145	1729		3700	1228			1458		

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MILWAUKEE SCHOOL OF ENGINEERING

TEST NONDESTRUCTIVE: X-RAY EMMISSION ANALYSIS
OF OIL SAMPLES
FILTER PATCHES

PROJECT NO. Pump #468F
DATE 5-7-83
TECHNICIAN B. Batley

DESCRIPTION Data taken is count rate corresponding to elements energy level.

COMMENTS Anode Status: 20ua; 35kv
50 micron vacuum
200 sec. run time

INSTRUMENTATION
ORTEC TEFA
MODEL 6110

Sample #	Cl	Si	S	Ca	Fe	Cu	Zn	Pb(Lα)	
146 & 147	1492		4444	1216	365		1274		
148 & 149	1542		3397	996	135		1101		
150 & 151	1550		3688	1164	208		1334		
150 & 151	1720		3656	1173	55		1209		
152 & 153	1501		3868	1143			1086		
154 & 155	1607		3333	1108			1124		
156 & 157	1733		3369	1152			1203		
158 & 159	1633		3461	1082			1156		
160 & 161	1608		3791	1126			1427		
162 & 163	1675		3470	1022			1221		
164 & 165	1742		3835	1139		80	1279		
166 & 167	1765		3835	1287			1664		

APPENDIX I

Photos of Pump Wear Analysis

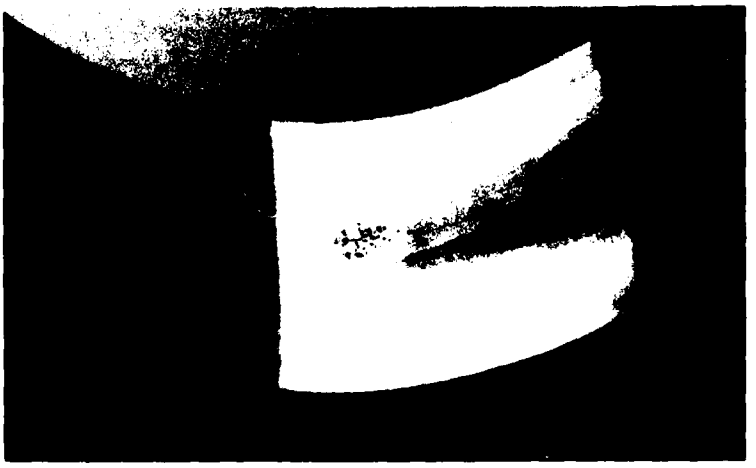
PHOTOS OF PUMP WEAR ANALYSIS

Analysis of Pump #468A

This pump was run at 2999.6 psid for the three hour break-in test; pumping an average flowrate of 25.3 gpm @ 2705.9 rpm. Average break-in efficiencies for this pump were: volumetric - 78%, mechanical - 92.6%, and an overall of 72.2%. While running on the wear test the pump started at 29.1 gpm @ 1209 psid and finished at 22.0 gpm @ 4795 psid. This pump had no catastrophic failures while running in the wear test; however, upon disassembling it was seen that the wear plates showed considerable wear.

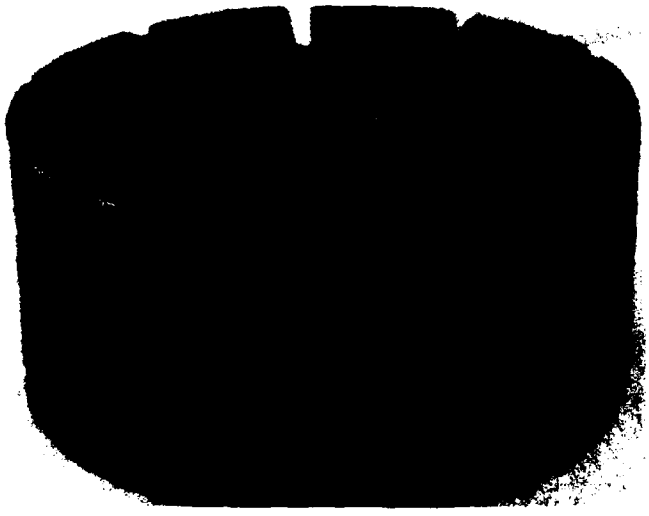
ANALYSIS OF PUMP #468A CONTINUED

Above - Overall view of the disassembled internal pump parts.



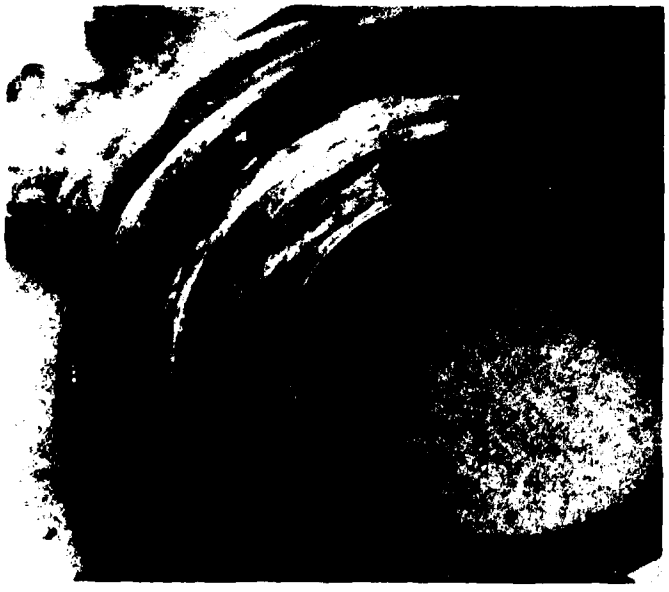
Above - Pitting is shown in the cam ring near the pressure section.

ANALYSIS OF PUMP #468A CONTINUED



Left - Rotor showing some wear marks on the top and circumferential face. There was also some bronze buildup on the top.

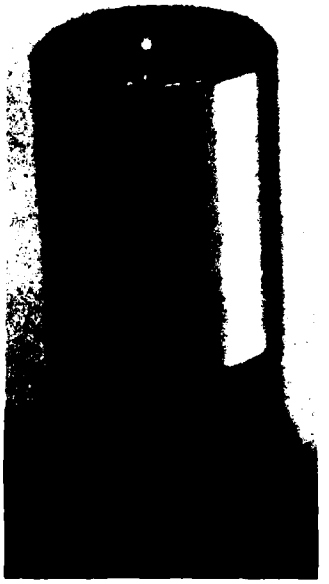
Right - Some wear on the small intra-vane and leading edge of the main vane can be seen.



Left - Pump shaft end wear plate showing scoring and pitting.

ANALYSIS OF PUMP #468A CONTINUED

Left - Shown is the pump inlet end wear plate showing grooves and pitting.



Above - Left, is the bronze bearing in the inlet support plate showing very much wear. Right, is the shaft end bronze bearing mating surface with excessive wear.

PHOTOS OF PUMP WEAR ANALYSIS

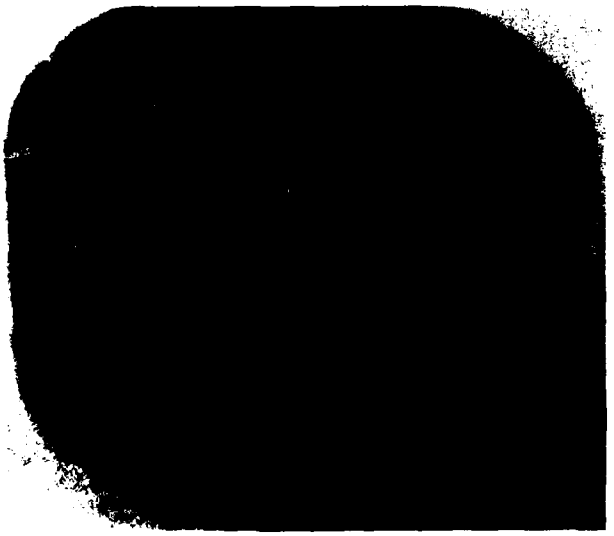
Analysis of Pump #468B

This pump was run at 2992.6 psid (ave.) for the three hour break-in test; pumping an average flowrate of 25.3 gpm @ 2713.7 rpm. Average break-in efficiencies for this pump were: volumetric - 77.7%, mechanical - 93.3%, and an overall of 72.5%. While running on the test stand the pump started at 27.8 gpm @ 1243 psid and ended at 20.6 gpm @ 4929 psid. There were no catastrophic failures in this pump however the wear plates did show considerable wear, of which some of the bronze was transferred to the rotor; this can be seen in the following photos.

ANALYSIS OF PUMP #468B CONTINUED

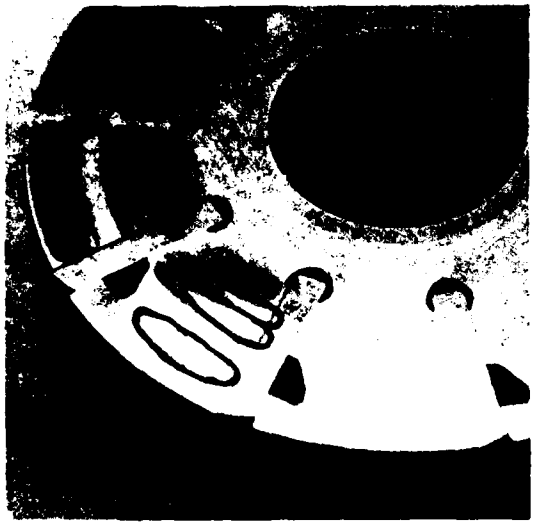
Left - Cam ring showing no signs of excessive wear.

Right - Both vane pieces showing noticeable wear on the leading edge of the main vane and light wear on the intra-vane.



Left - Overall view of rotor showing wear marks on the circumferential surface; and bronze build-up on the top.

ANALYSIS OF PUMP #468B CONTINUED



Left - Closeup up of rotor top; the dark and bright areas circled are bronze buildup off of the wear plates.

Above - The bottom side of rotor showing bronze buildup from the wear plates.

ANALYSIS OF PUMP #468B CONTINUED

Left - Pump shaft end wear plates showing light wear grooves and surface wear (shiny areas).

Right - Pump inlet end wear plate showing deep and numerous grooves with pitting.

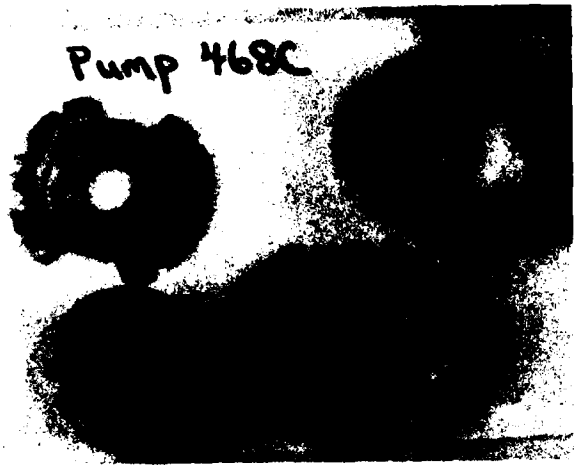
Above - Pump shaft bearing surface for bronze bearing and bearing in the inlet support plate. Some wear is shown on both surfaces.

PHOTOS OF PUMP WEAR ANALYSIS

Analysis of Pump #468C

This pump was run at 3003.5 psid for the three hour break-in test; pumping an average flowrate of 26.5 gpm @ 2725.4 rpm. Average break-in efficiencies for this pump were: volumetric - 81.8%, mechanical - 92.8%, and an overall of 75.3%. While running on the wear test the pump started at 29.3 gpm @ 1230 psid and ended at 24.6 gpm @ 4430 psid. There were no catastrophic failures in this pump, however, the wear plates did show considerable wear.

ANALYSIS OF PUMP #468C CONTINUED



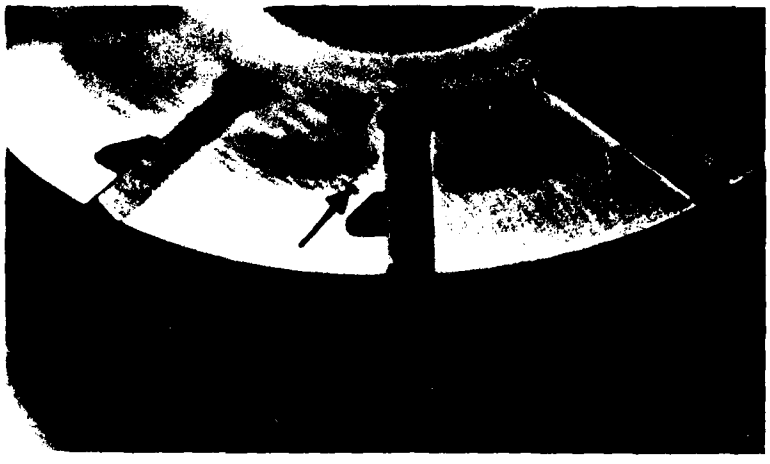
Left - Overall view of disassembled pump.

Right - Photo of cam ring showing no signs of excessive wear.

Above - Photos showing wear lines and wear on leading edge of vanes.

ANALYSIS OF PUMP #468C CONTINUED

Left - Rotor with wear rings on the circumferential face and bronze buildup on the top. (The dark areas).



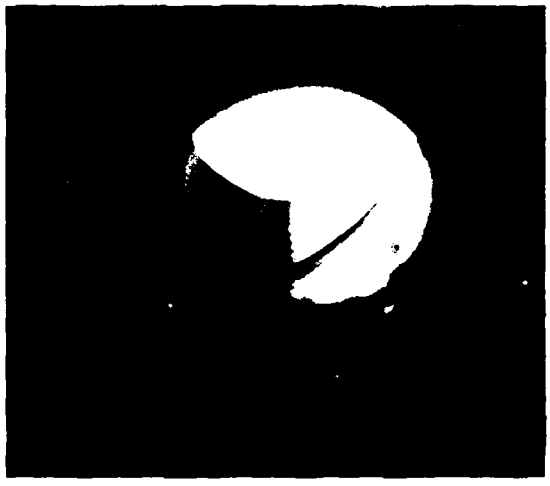
Above - Arrow points to bronze particles on rotor top.

ANALYSIS OF PUMP #468C CONTINUED

Above - Wear plate (pump shaft end) with wear marks from rotor and vanes.

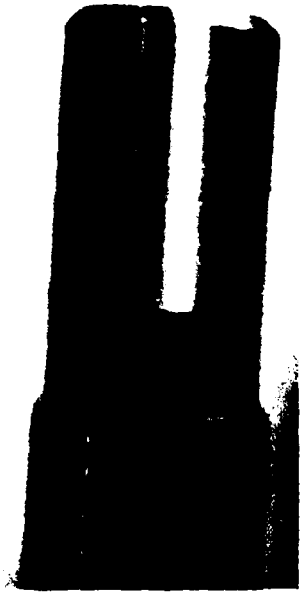
Below - Wear plate (pump inlet end) with excessive wear.

ANALYSIS OF PUMP #468C CONTINUED



Left - Bronze bearing inlet support plate showing grooves caused by wear

Right - Shaft end bronze bearing mating surface with wear ring; no grooves noticeable to touch.

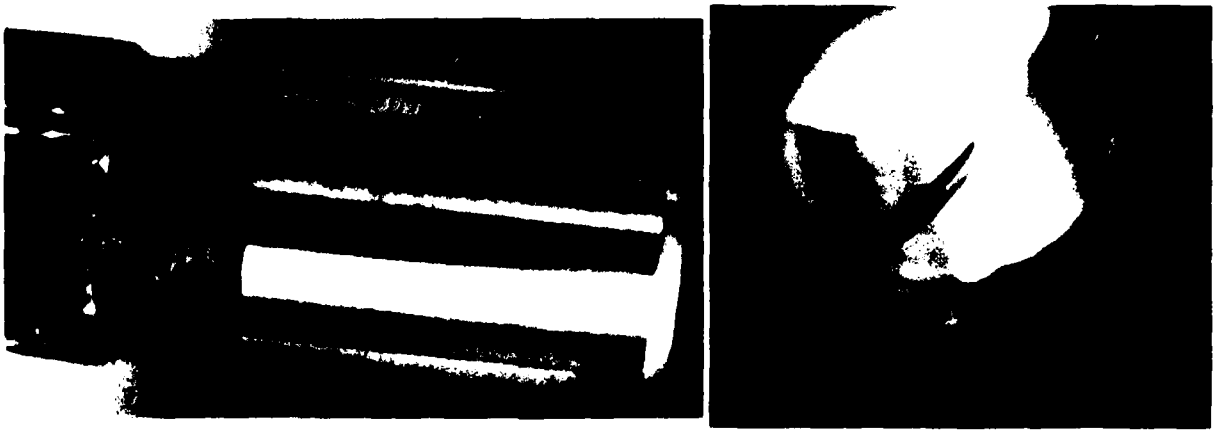


PHOTOS OF PUMP WEAR ANALYSIS

Analysis of Pump #468D

This pump was run at 594.8 psid for the three hour break-in test; pumping an average flowrate of 30.5 gpm @ 2702.9 rpm. Average break-in efficiencies for this pump were: volumetric - 94.1%, mechanical - 79.4%, and an overall of 74.8%. While running on the wear test setup the pump started at 29.0 gpm @ 1241 psid and ended at 22.2 gpm @ 4659 psid. This pump experienced no catastrophic failures.

Above - Pump upper wear plate showing wear groves and very little pitting. Note, the arrow pointing out the high pressure leakage path, from between the wear plate and rotor.

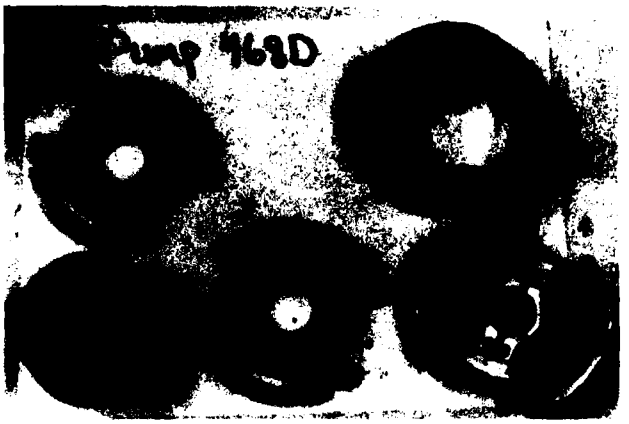


Above - Pump shaft bearing surface for bronze bearing and bearing in the inlet support plate. Some wear is shown on both surfaces.

Right - Rotor showing wear markings on the circumferential face, and light wear on the side.

Above - Pump shaft end wear plate showing light wear patterns.

ANALYSIS OF PUMP #468D CONTINUED



Left - Overall view of disassembled pump.

Right - Cam ring with some light wear.

Left - Wear lines can be seen on both vanes, also wear on leading edge of the main vane.

PHOTOS OF PUMP WEAR ANALYSIS

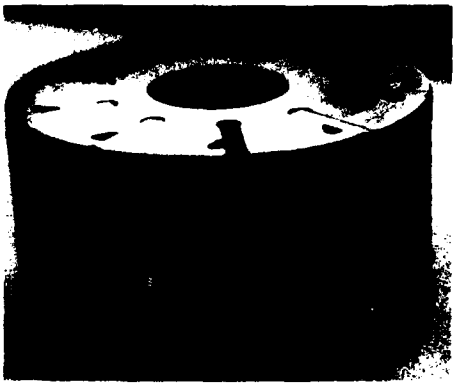
Analysis of Pump #468E

This pump was run at 591.4 psid for the three hour break-in test; pumping an average flowrate of 30.7 gpm @ 2703.2 rpm. Average break-in efficiencies for this pump were: volumetric - 94.8%, mechanical -79%, and an overall of 75%. While running on the wear test the pump started at 28.8 gpm @ 1245 psid and ended at 27.2 gpm @ 4444 psid. The reason that this pump was not run up to 5000 psid was that the test stand shut down unexpectedly. The super charge pump then caused the test pump's shaft seal to blow out; due to this the pump was pulled and disassembled.

ANALYSIS OF PUMP #468E CONTINUED

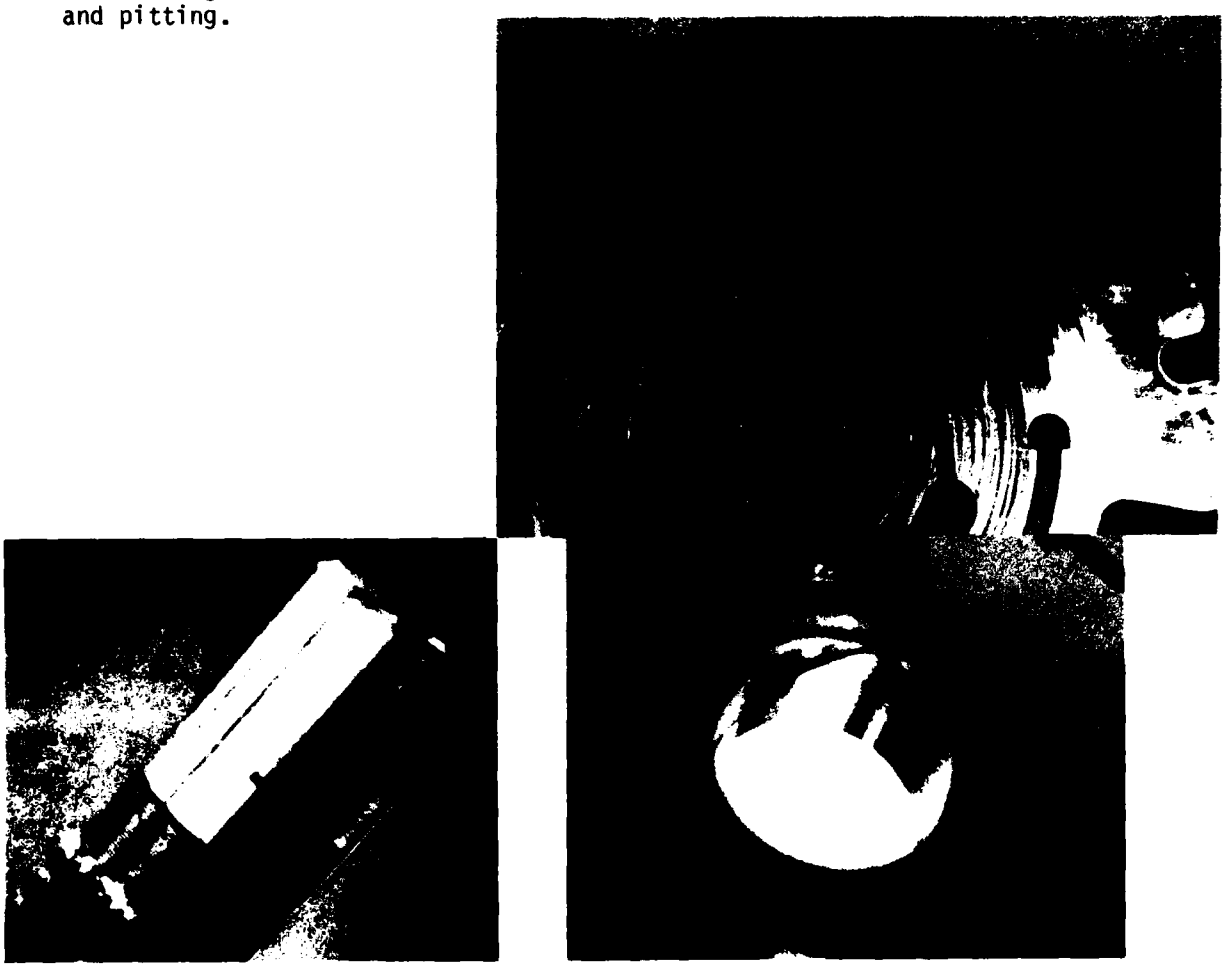
Left - Photo of cam ring showing no signs of excessive wear.

Right - Rotor with wear rings on the circumferential face and some bronze buildup on the top.



Left - Pump shaft end wear plate with grooving and pitting marks.

Right - Pump inlet end wear plate with a large number of deep grooves and pitting.



Above - Left, is the bronze bearing in the inlet support plate showing very much wear. Right, is the shaft end bronze bearing mating surface with excessive wear.

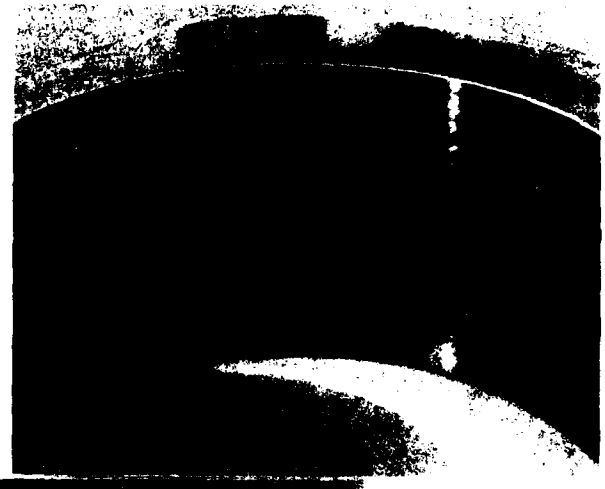
PHOTOS OF PUMP WEAR ANALYSIS

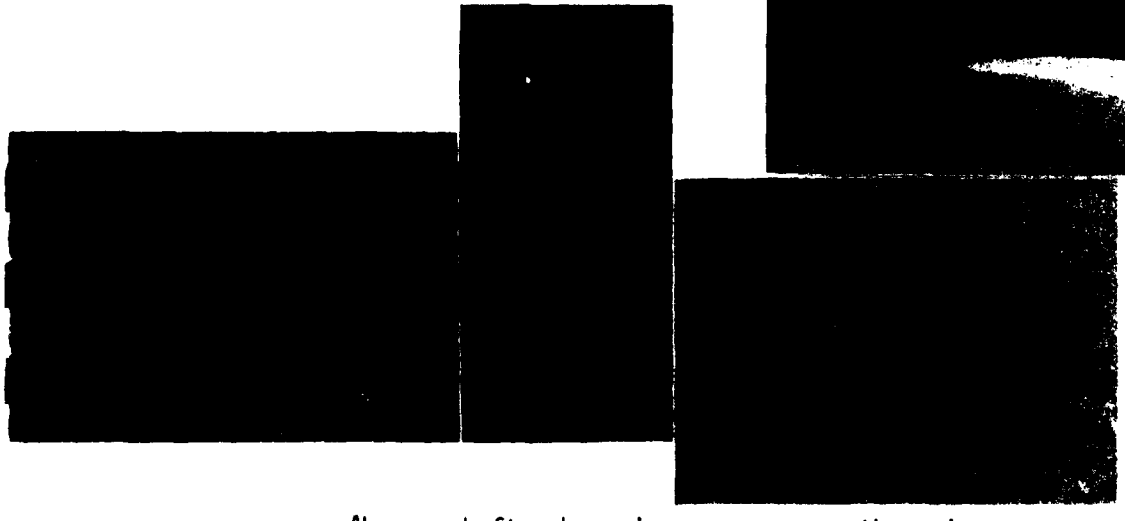
Analysis of Pump #468F

This pump was run at 600 psid for the three hour break-in test; pumping an average flowrate of 31.0 gpm @ 2707.8 rpm. Average break-in efficiencies for this pump were: volumetric - 95.6 %, mechanical - 79.3%, and an overall of 75.8%. While running the wear test the pump started at 29.6 gpm @ 1388 psid and ended at 25.86 gpm @ 4956 psid. This pump experienced a break in the cam ring.

Left - Cam ring inlet section showing a crack going all the way through the ring; and some cavitation marks to the left of the inlet passage.

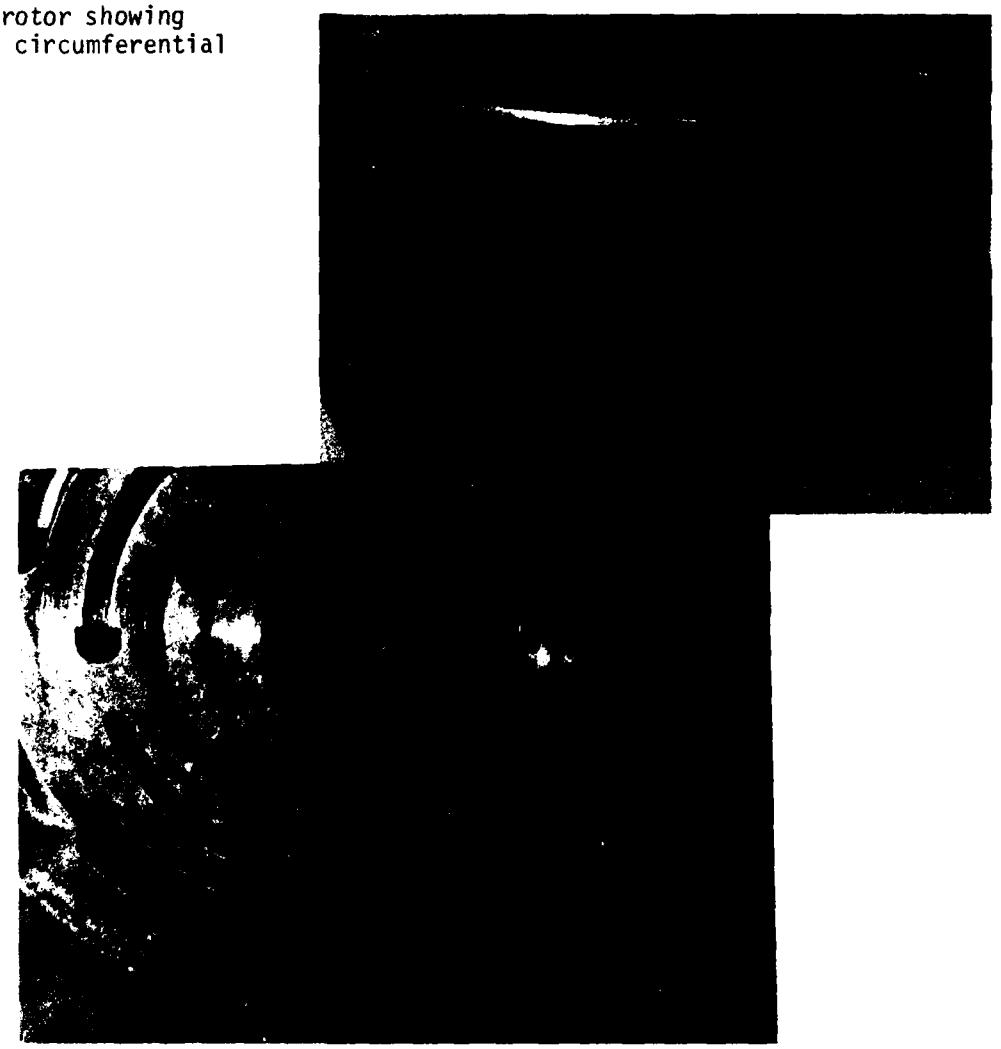
Right - Cam ring crossover from inlet to outlet section showing crack in cam ring and chatering marks to the right.





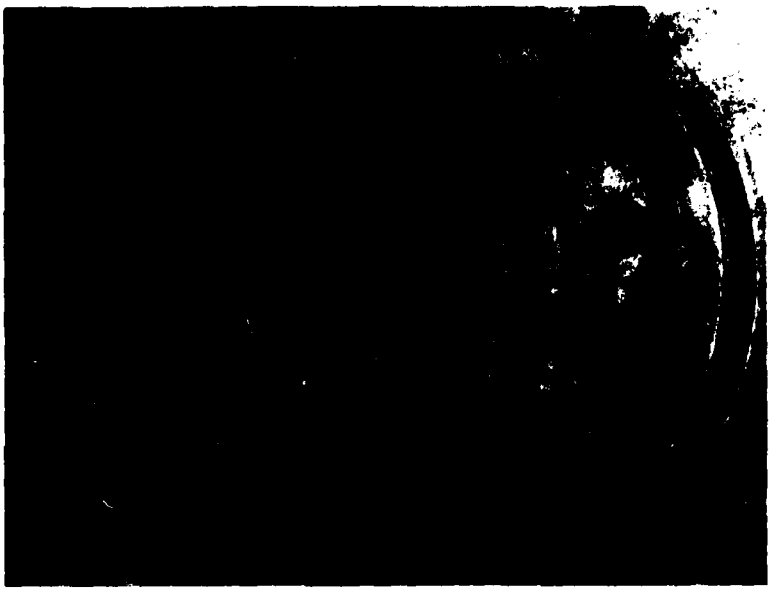
Above - Left, shown is some wear on the main vane and intra-vane, center; wear experience on the leading edge of the vane, right; shown is some wear on the main vane and intra-vane.

Right - Pump rotor showing light wear on circumferential surface.

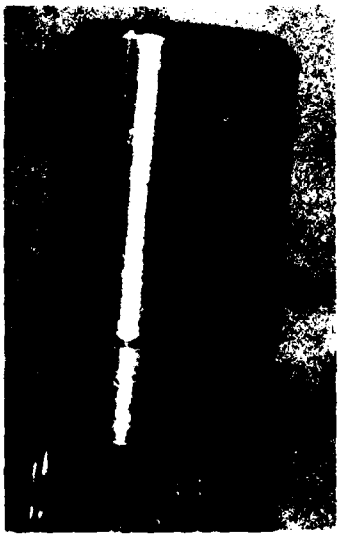


Above - Pump shaft end wear plate showing wear patterns (light and dark areas) and some small grooves.

ANALYSIS OF PUMP #468F CONTINUED



Above - Pump inlet end wear plate showing wear patterns (light and dark areas) and some small grooves.



Above - Pump shaft bearing surface for bronze bearing and bearing in the inlet support plate. Some wear is shown on both surfaces.

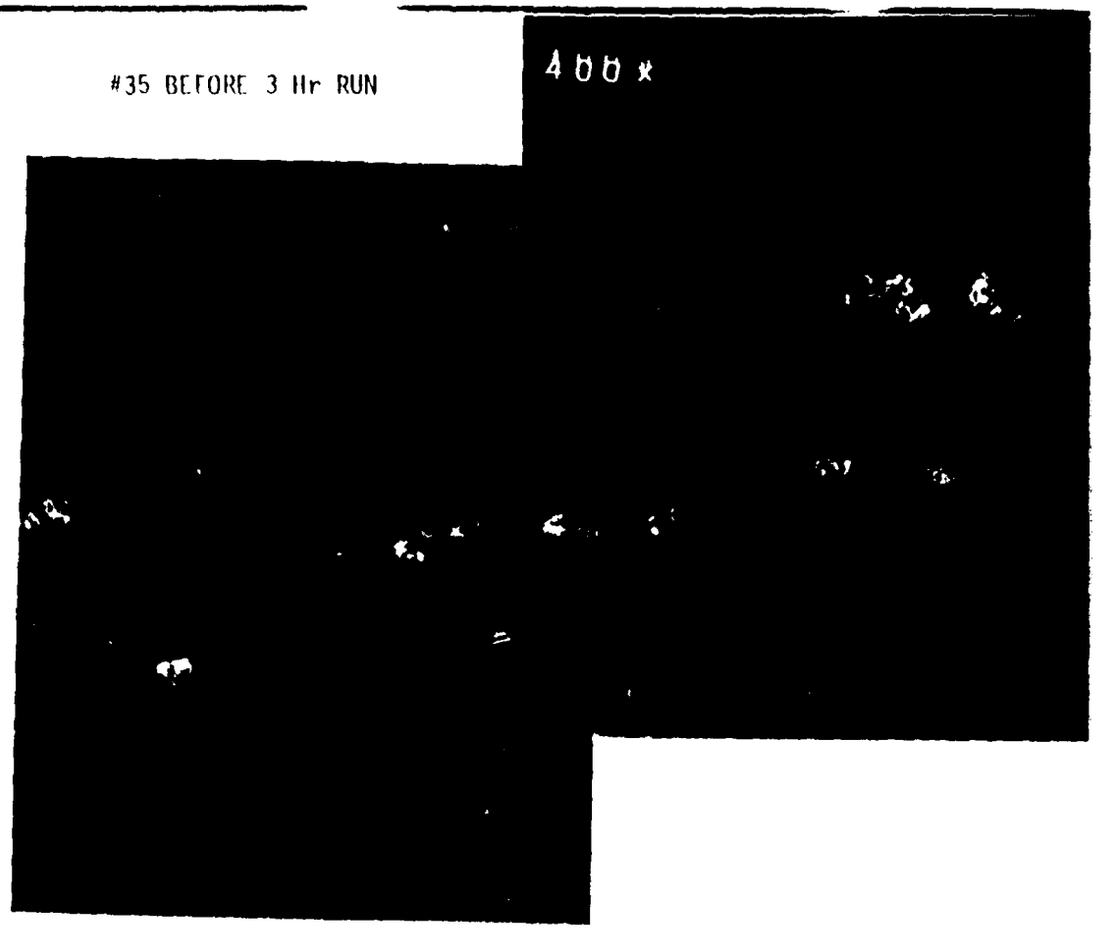
APPENDIX J

Ferrographic Data

Samples from the outlets #73 to #167 wear much cleaner than the earlier samples. The amount of rubbing wear was also lower. The increase in spheres was probably from the metal melting off the vanes instead of rubbing off.

we were unable to do the ferrograph DR on samples #137 to #167 due to mechanical problems. Ferrograms were done on samples #123 and !153 using much larger volumes than normal (10-30ml compaired to the normal 3ml) . The results were an increase in the large particles and cutting wear with some brass not picked up in the normal sample. There was also an increase in the non-ferrous wear down around 40-20mm.

#35 BEFORE 3 Hr RUN

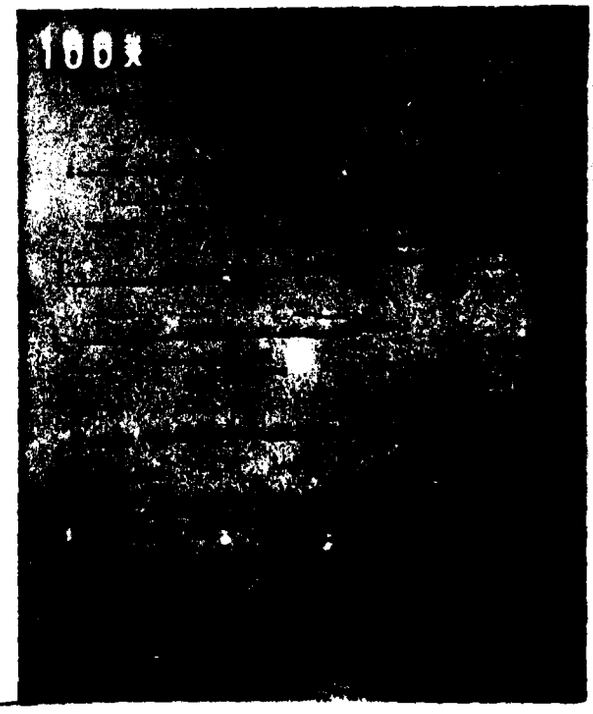


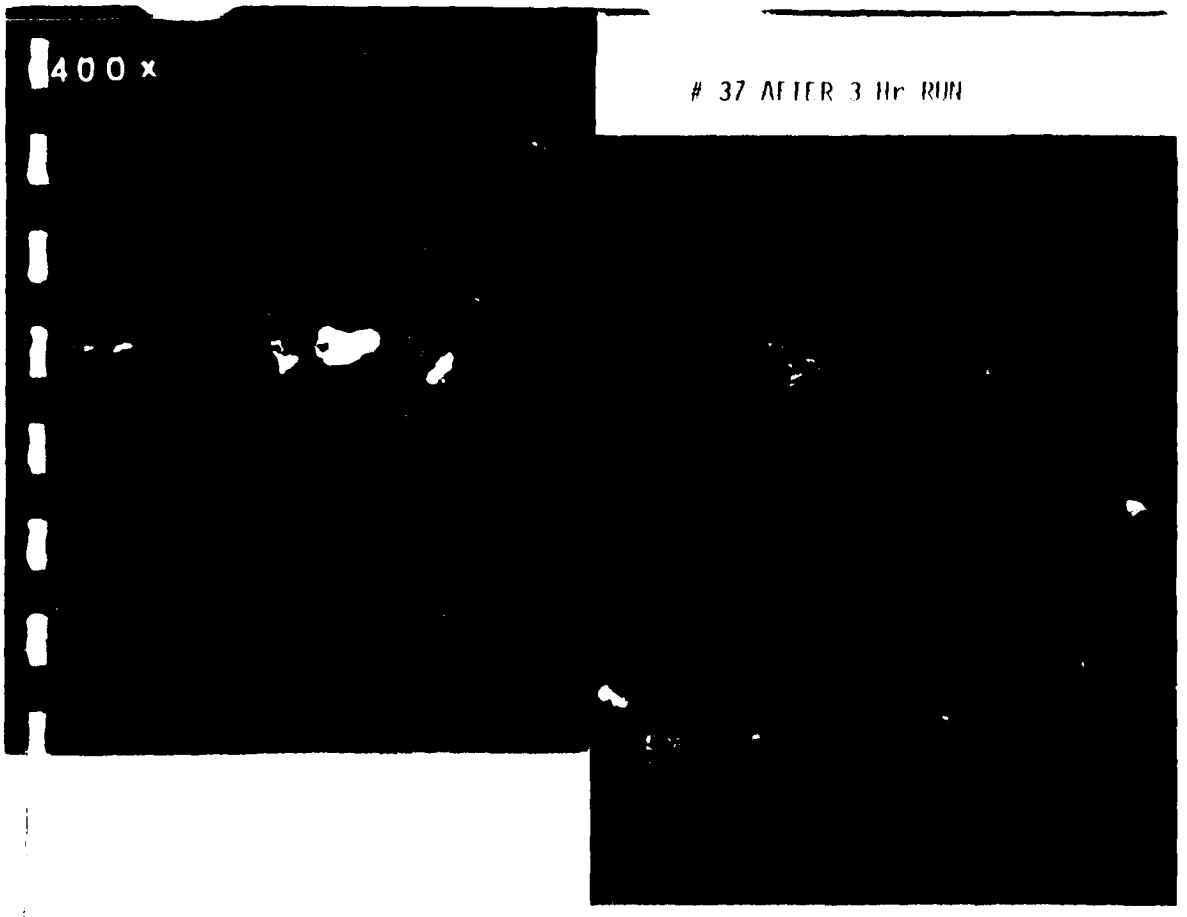
micron size 5 10 20 30
count 1186 231 33 9

ferrograph DR L/S
5.5/3.4

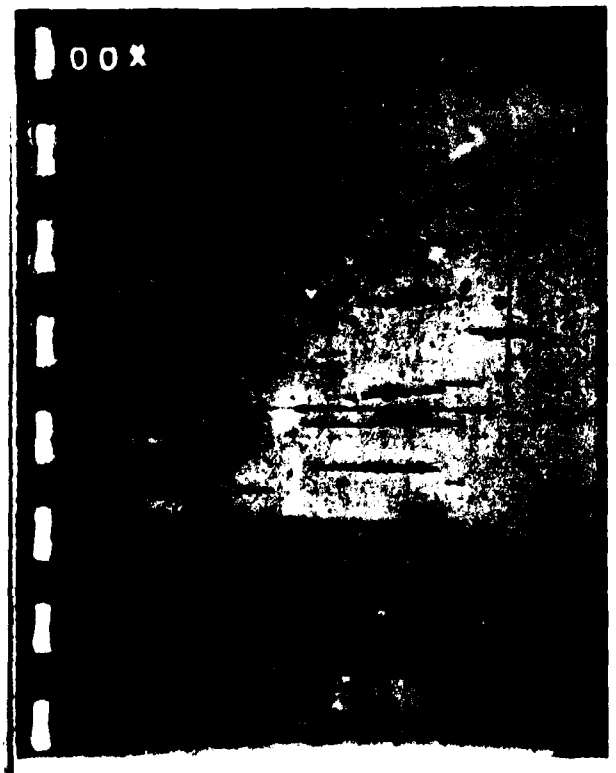
spectro Fe Cu Al Si
ppm 6 4 3 6

ferrogram;
few chunks and spheres





37 AFTER 3 Hr RUN



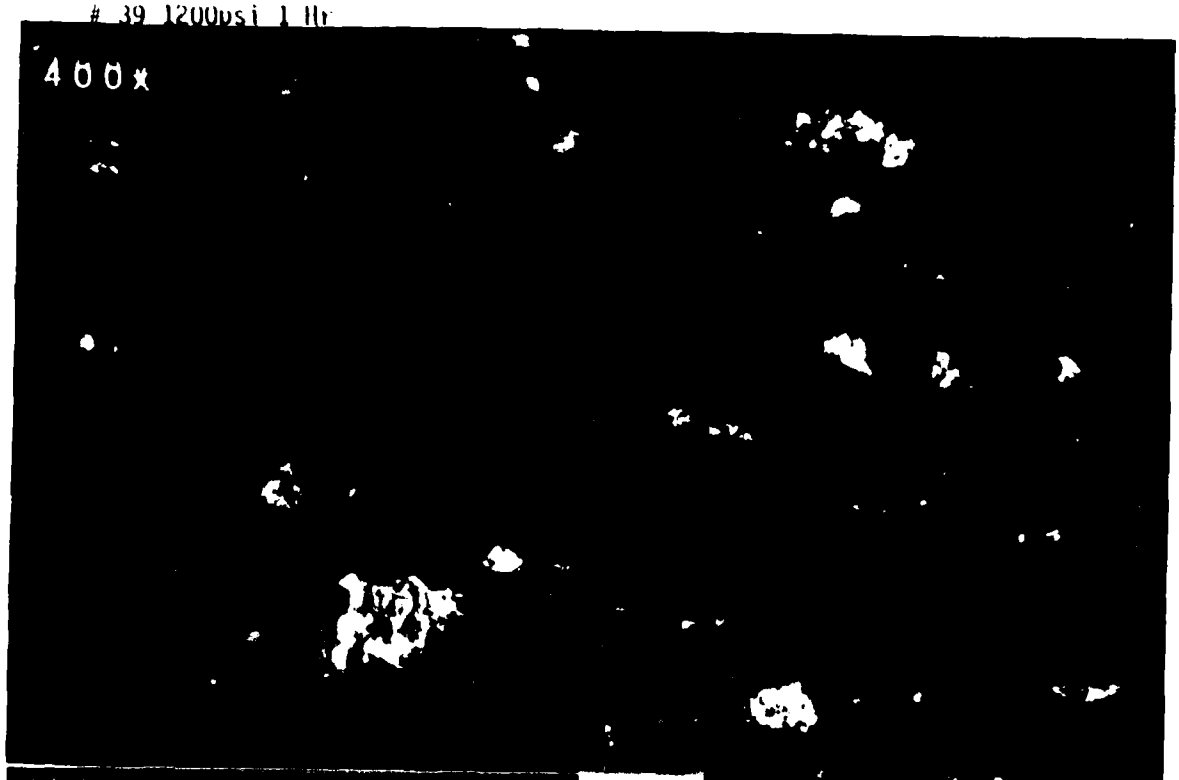
micron size	5	10	20	30
count	545	106	18	6

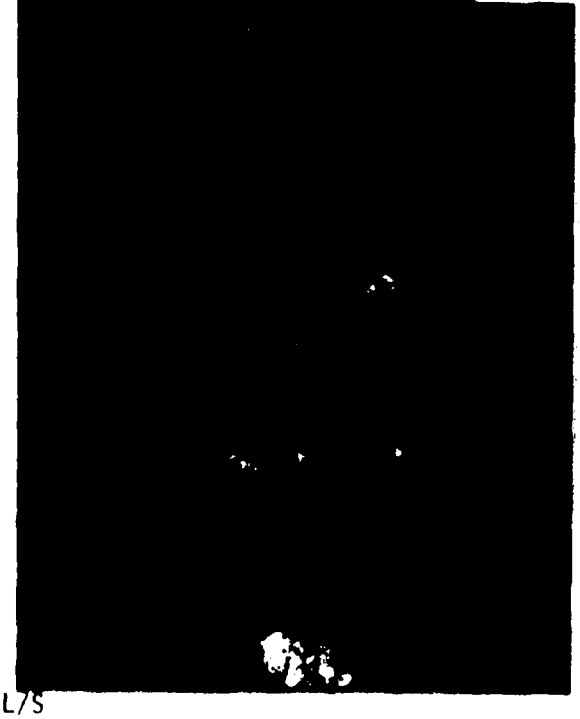
ferrograph DR L/S
5.1/3.5

spectro	Fe	Cu	Al	Si
ppm	6	5	3	7

ferrogram;
few chunks and very few spheres

39 1200psi 1 Hr





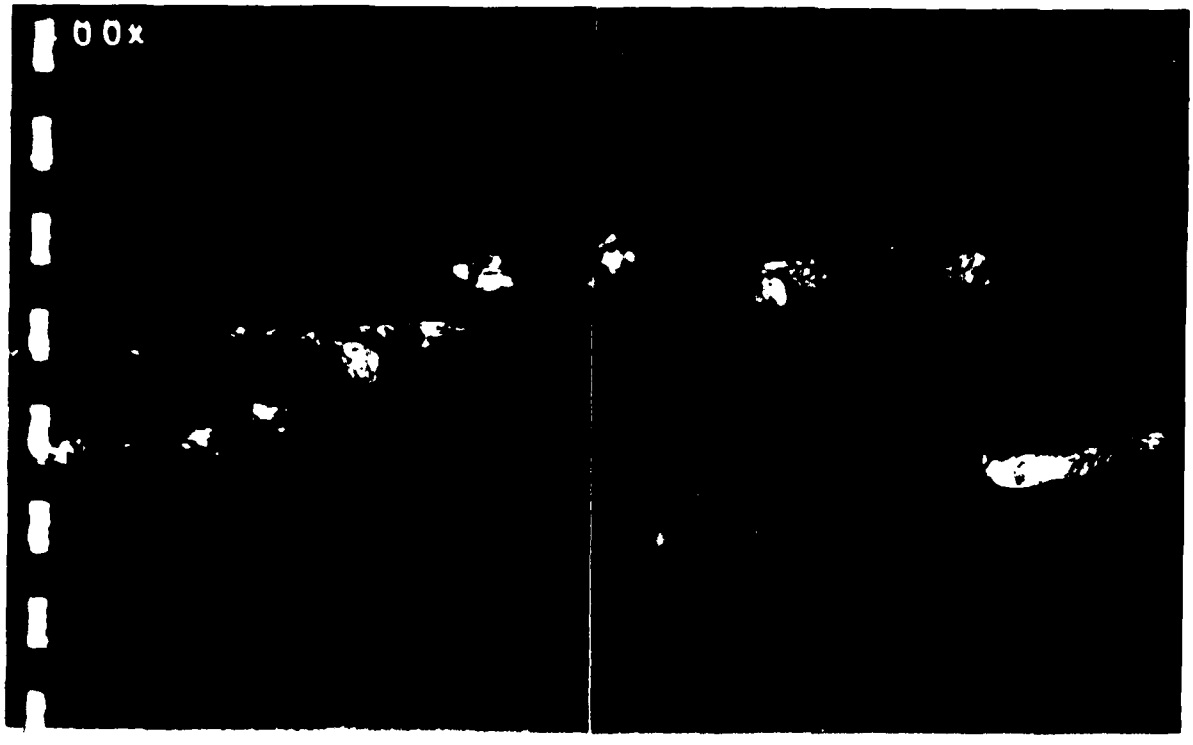
micron size	5	10	20	30
count	12370	2622	416	129

spectro	fe	Cu	Al	Si
ppm	6	5	3	8

ferrograph DR L/S
12.8/3.2

ferrogram; sand, D-M-O, spheres, chunks and large rubbing wear

41 1200 psi 2 Hr.



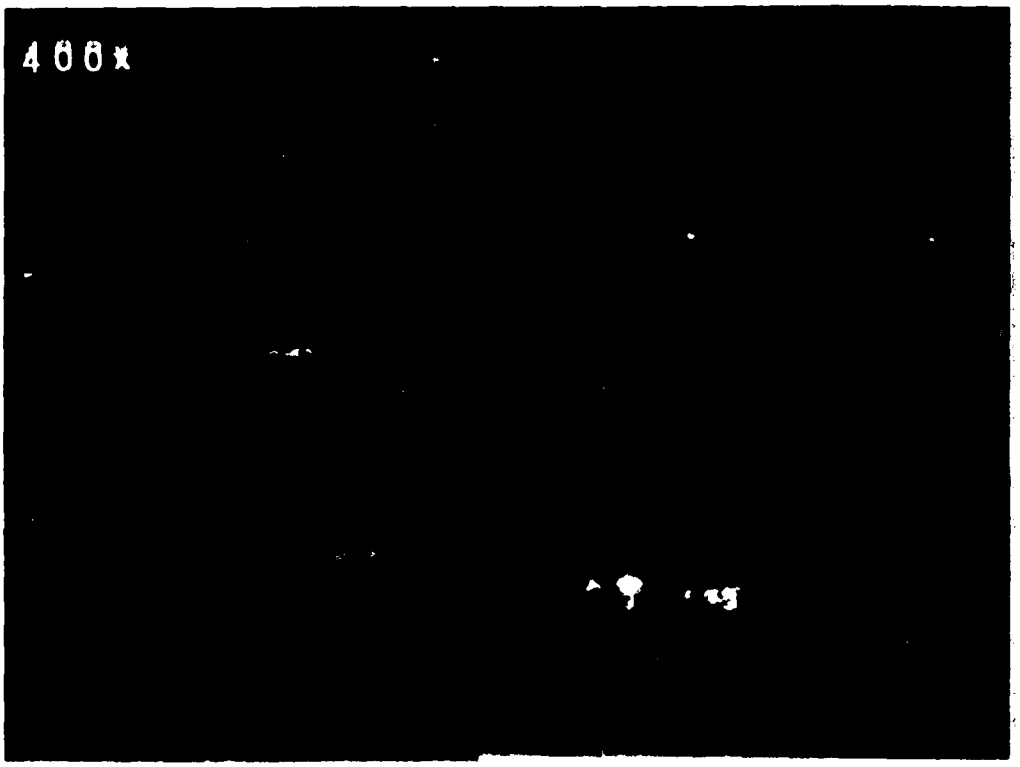
micron size	5	10	20	30
count	973	184	30	11

ferrograph DR L/S
3.7/1.8

spectro	Fe	Cu	Al	Si
ppm	6	5	3	7

ferrogram; cleaner than #39, moderate chunks few spheres.

43 1200psi 3Hr.



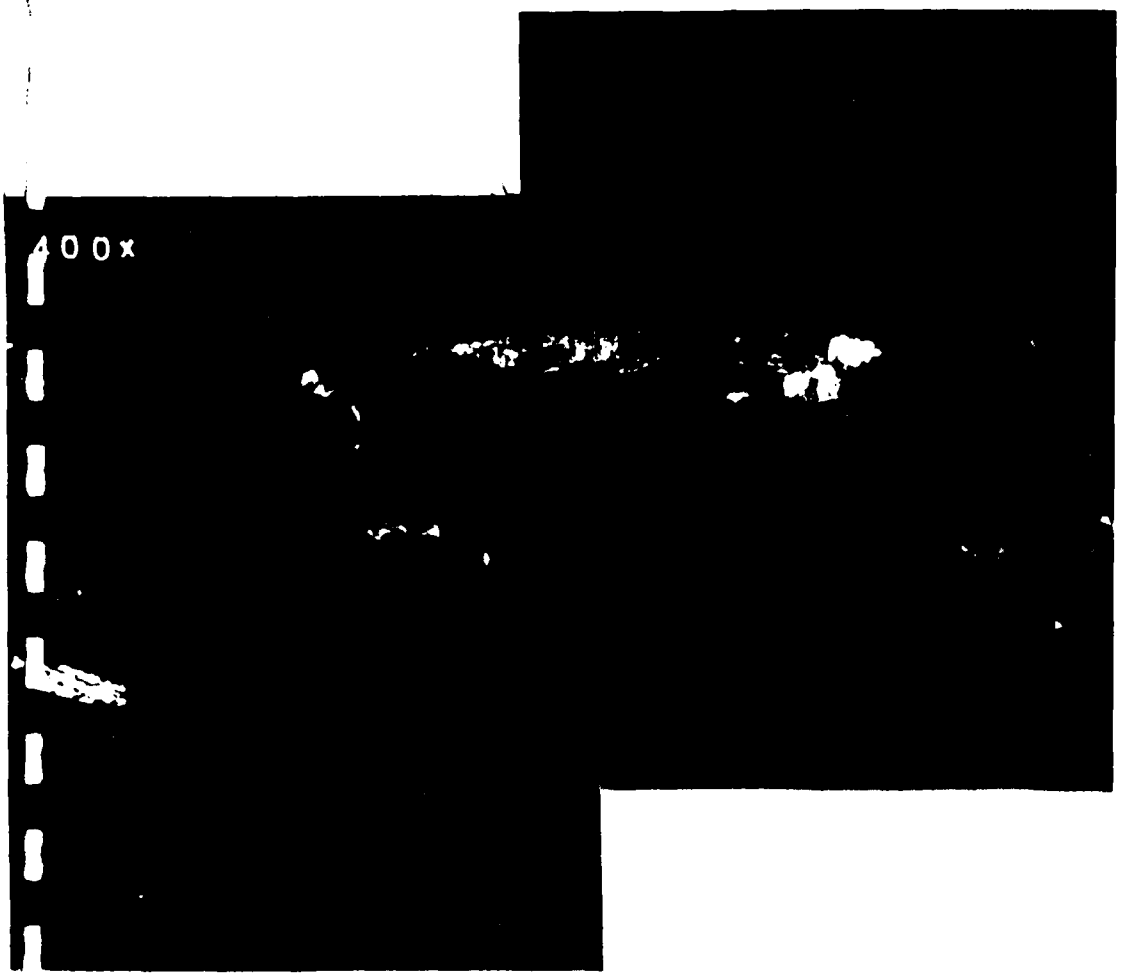
micron size 5 10 20 30
count 728 125 22 6

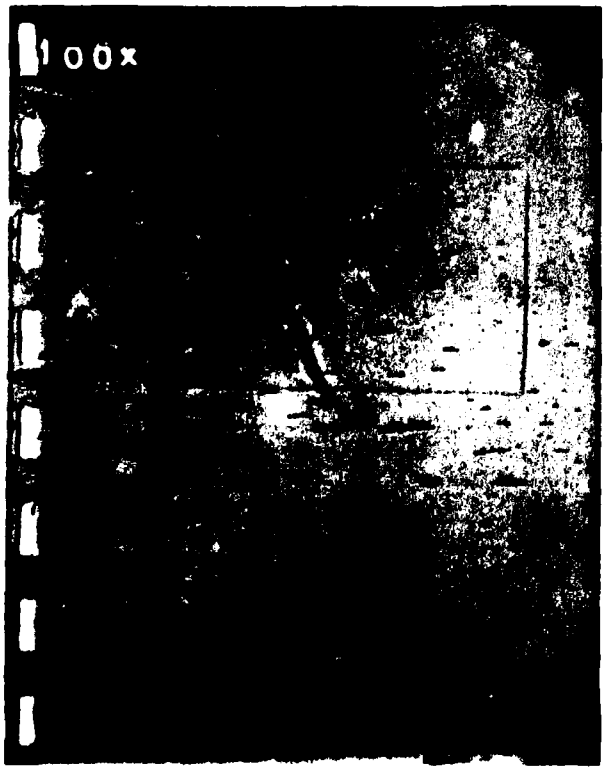
ferrograph DR L/S
2.9/1.3

spectro Fe Cu Al Si
ppm 6 5 3 8

ferrogram; some severe wear particles, mostly normal.

45 1200 psi 4 Hr.





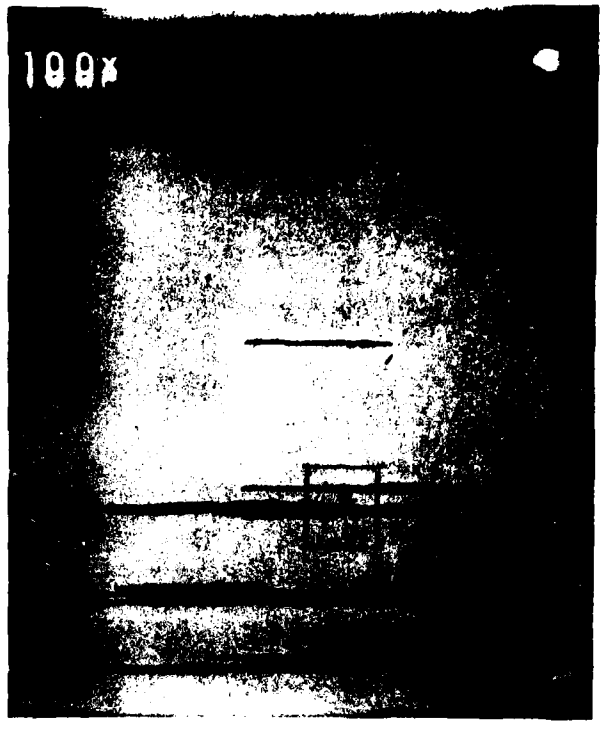
micron size	5	10	20	30
count	814	162	30	9

ferrograph DR L/S
5.1/1.5

spectro	Fe	Cu	Al	Si
ppm	6	5	3	6

ferrogram; few chunks, some non-ferrous, marginal amount of severe wear.

#47 1400psi 1Hr.



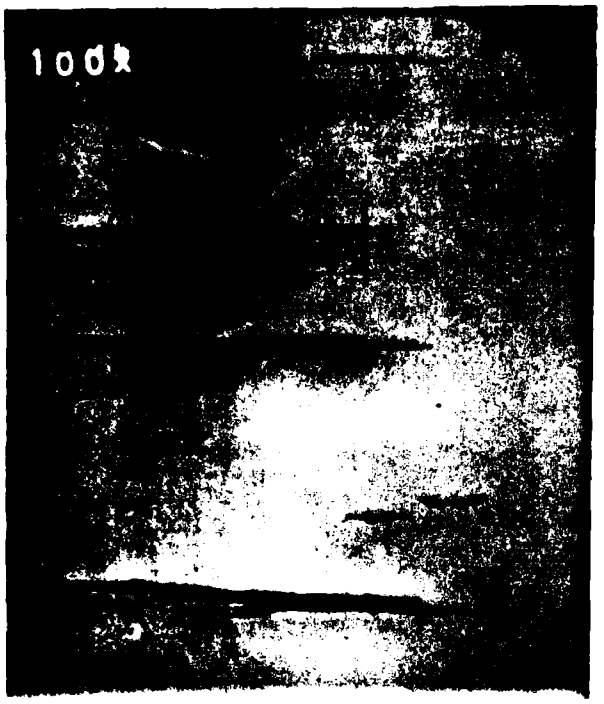
micron size 5 10 20 30
count 327 101 37 21

ferrograph DR L/S
4.6/2.7

spectro Fe Cu Al Si
ppm 5 4 0 5

ferrogram; normal, few small spheres.

#49 1400psi 2Hr.



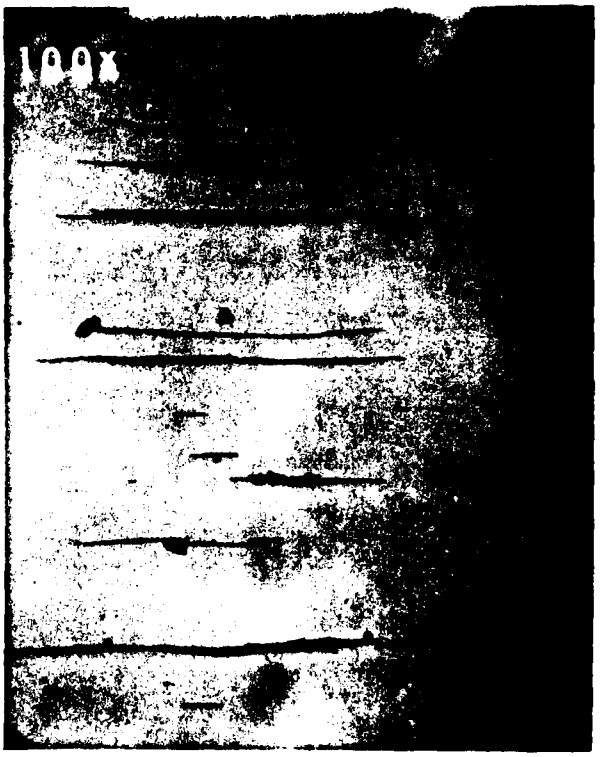
micron size	5	10	20	30
count	237	57	12	5

ferrograph DR L/S
4.1/2.5

spectro	Fe	Cu	Al	Si
ppm	4	4	0	22

ferrogram; few small spheres and some tempered cutting wear, other wise normal.

#51 1400psi 3Hr.



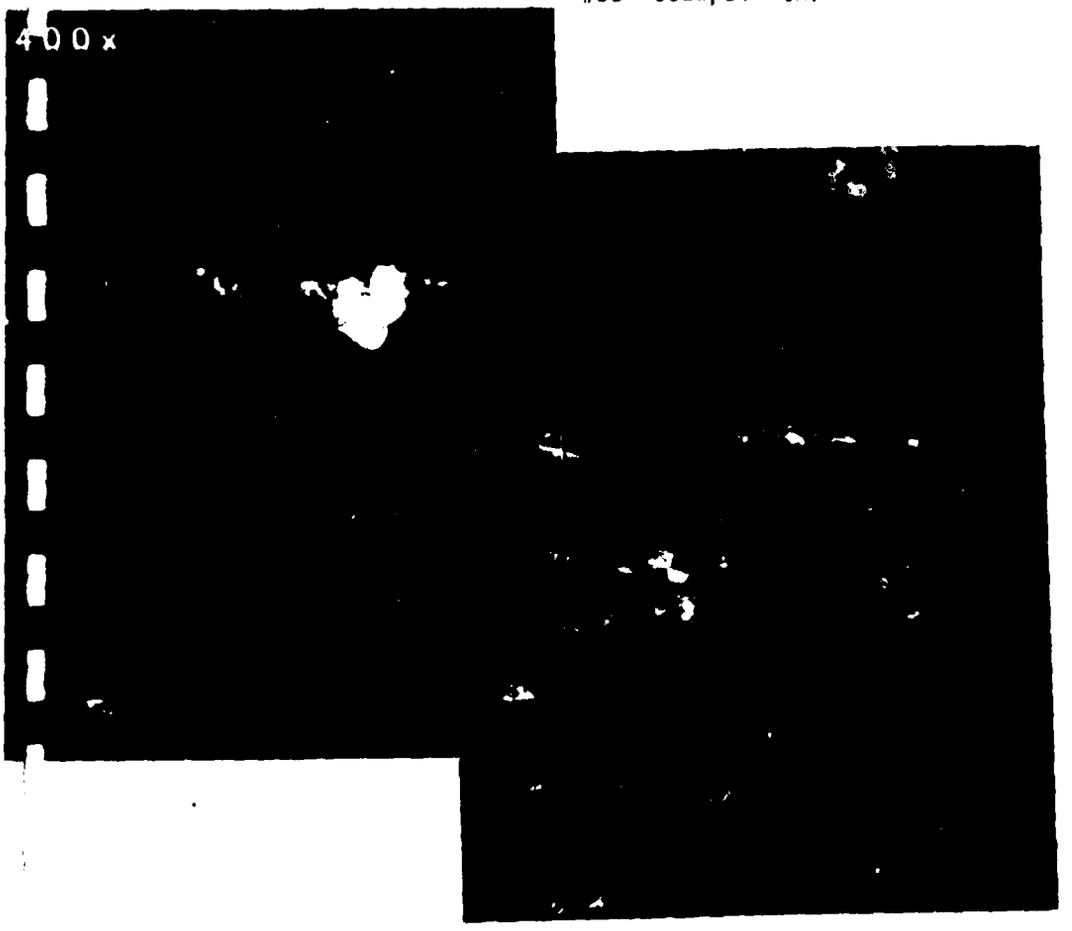
micron size	5	10	20	30
count	283	65	10	2

ferrograph DR L/S
4.5/2.5

spectro	Fe	Cu	Al	Si
ppm	4	3	0	18

ferrogram; normal.

#53 1600psi 1Hr.



micron size 5 10 20 30
count 26559 6544 1028 298

ferrograph DR L/S
8.3/2.2

spectro Fe Cu Al Si
ppm 5 5 3 49

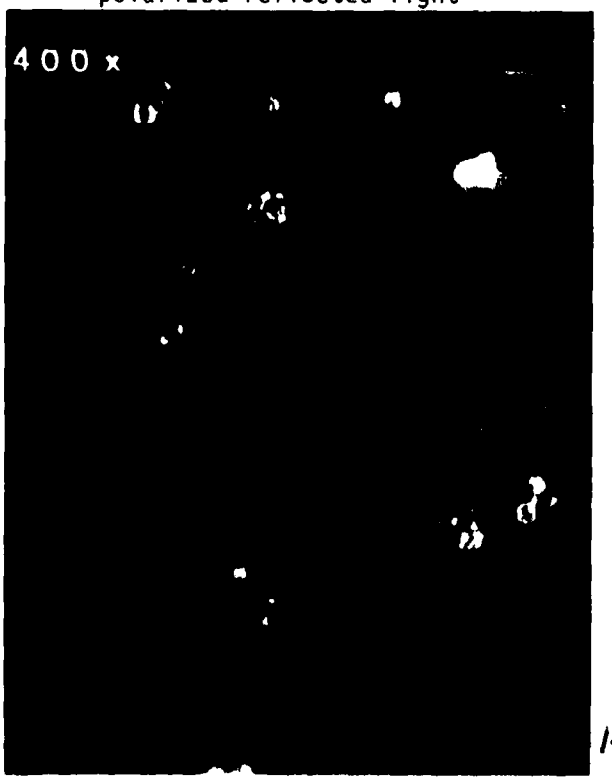
ferrogram; heavy crystalline contamination, heavy spheres, moderate chunks and cutting wear. Large flakes of brass, moderate.

crystalline contamination

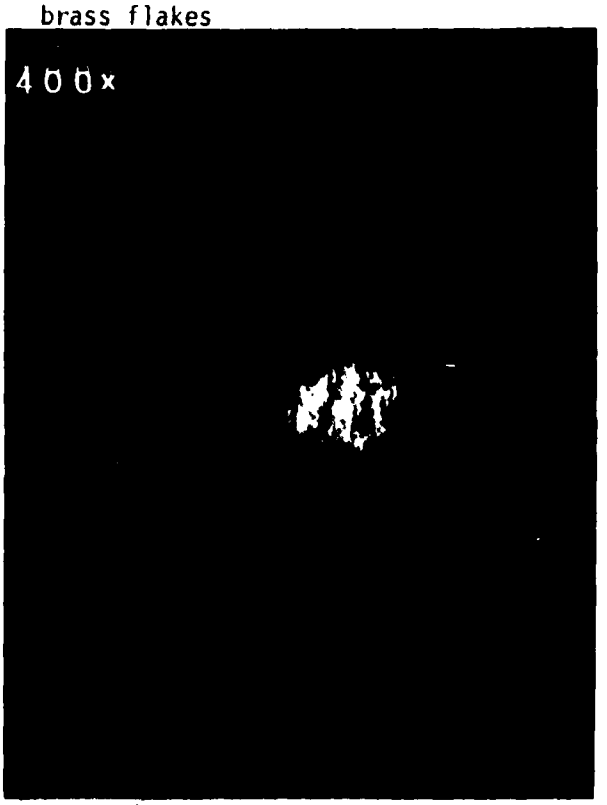
S.E.M. photo

S.E.M. photo

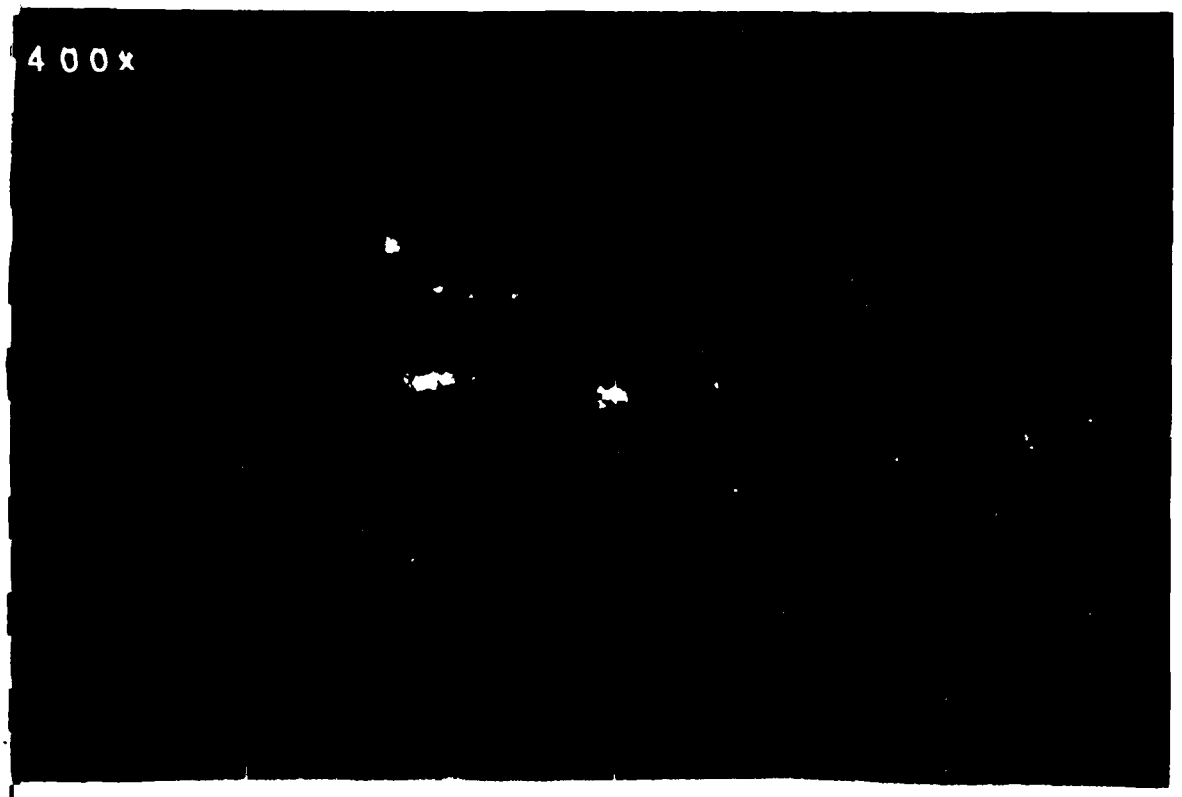
polarized reflected light



brass flakes



#55 1600psi 2Hr.



micron size	5	10	20	30
count	1238	327	59	18

ferrograph DR L/S
3.2/2.0

spectro	Fe	Cu	Al	Si
ppm	5	3	0	9

ferrogram;few crystalline particles, some spheres, much cleaner than #53. sample is normal

#57 1600psi 3Hr.

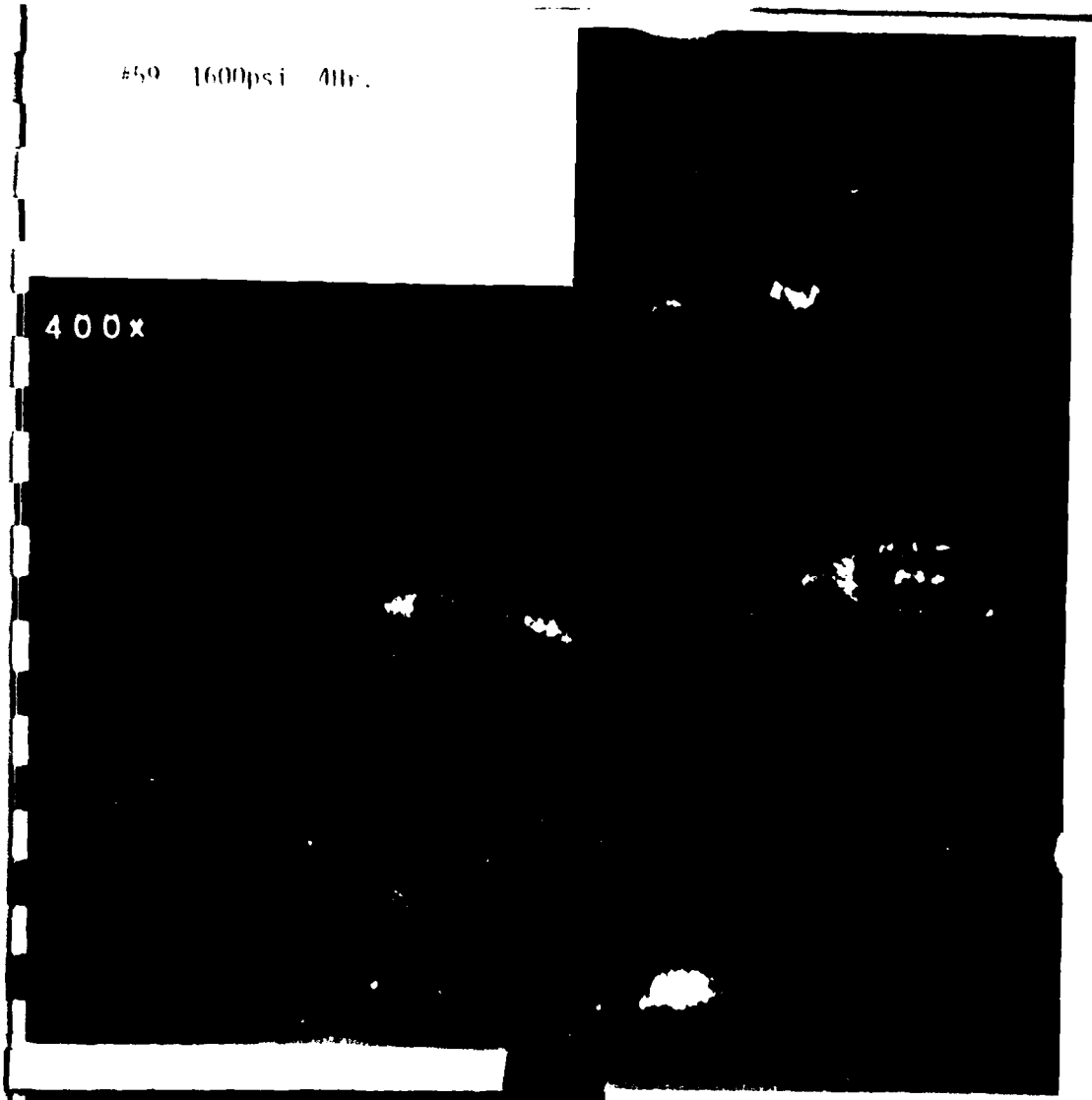
microns size 5 10 20 30
ount 1070 287 53 17

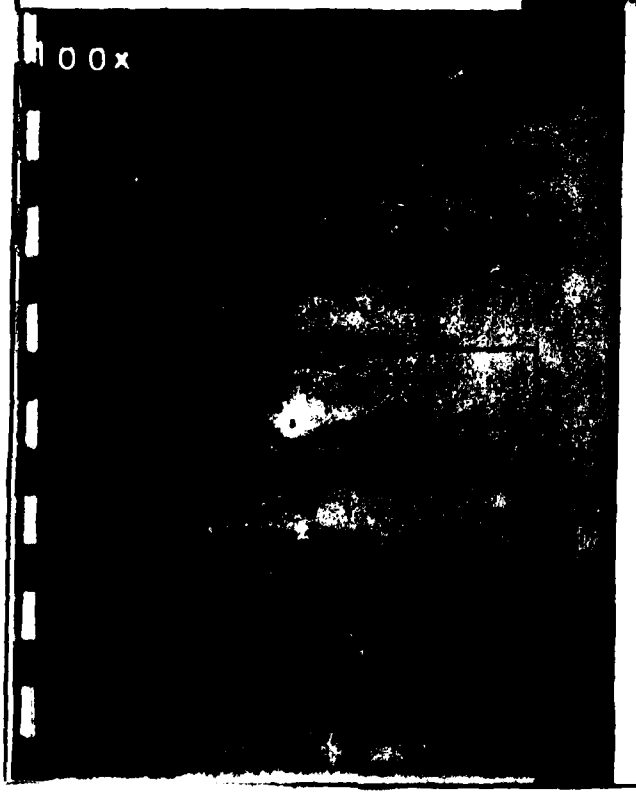
ferrograph DR L/S
4.8/2.2

spectro Fe Cu Al Si
ppm 4 3 2 6

errogram; normal, little debris, spheres
chunks, very little cutting wear.

#59 1600psi 4Hr.





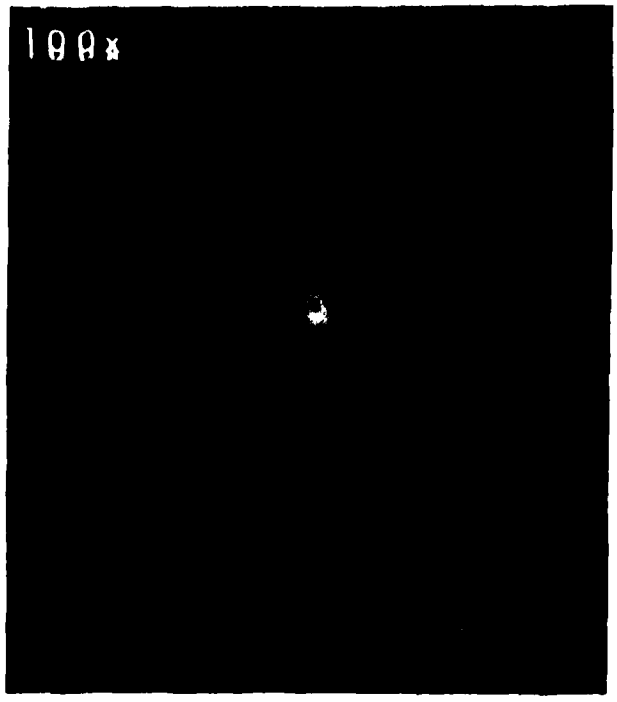
micron size	5	10	20	30
count	883	218	36	11

ferrograph DR L/S
3.6/2.2

spectro	Fe	Cu	Al	Si
ppm	5	3	0	7

ferrogram; mostly normal, few chunks and few non-ferrous particles up to 20 microns. Same particles were in the inlet sample but larger, 200 microns.

61 1600psi 5Hr.



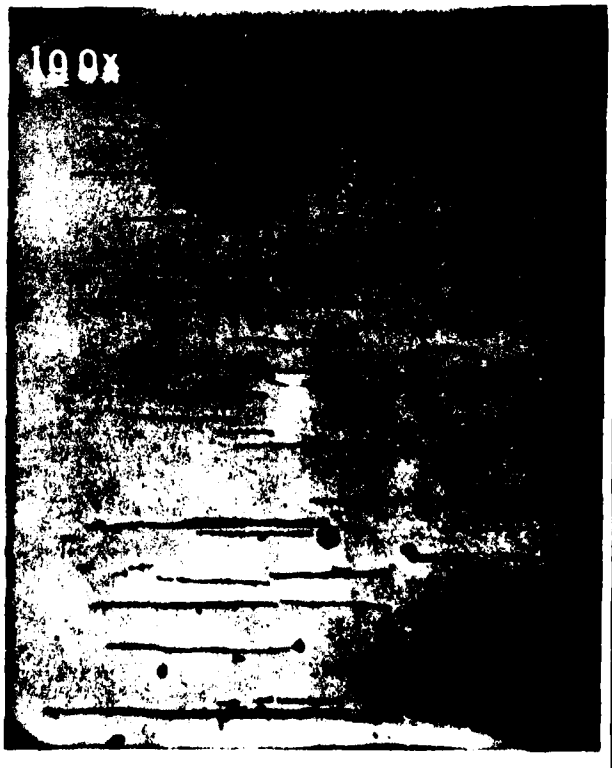
micron size 5 10 20 30
count 1155 283 49 18

ferrograph DR L/S
3.7/2.0

spectro Fe Cu Al Si
ppm 5 3 0 8

ferrogram; normal, just small rubbing wear.

#63 1800psi 1Hr.



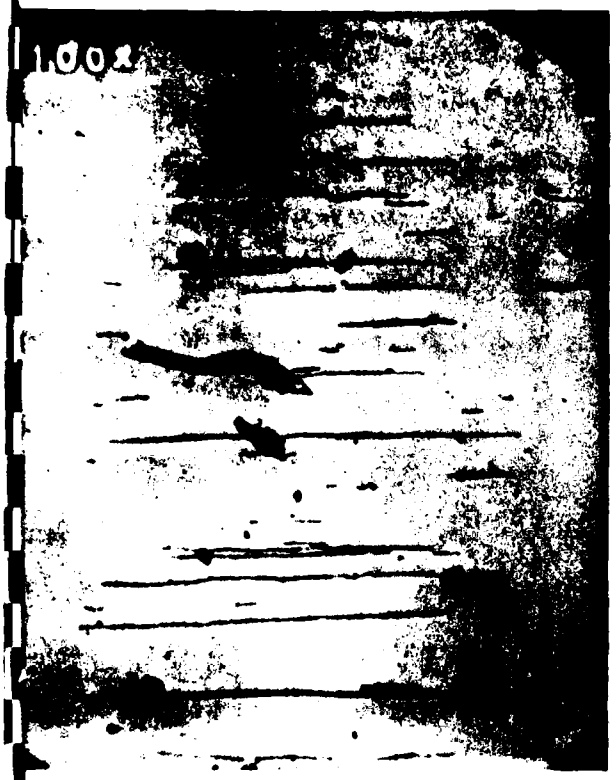
micron size 5 10 20 30
count 506 155 36 11

ferrograph DR L/S
3.4/2.0

spectro Fe Cu Al Si
ppm 4 3 0 5

ferrogram; normal, some debris.

#65 1800psi 2Hr.



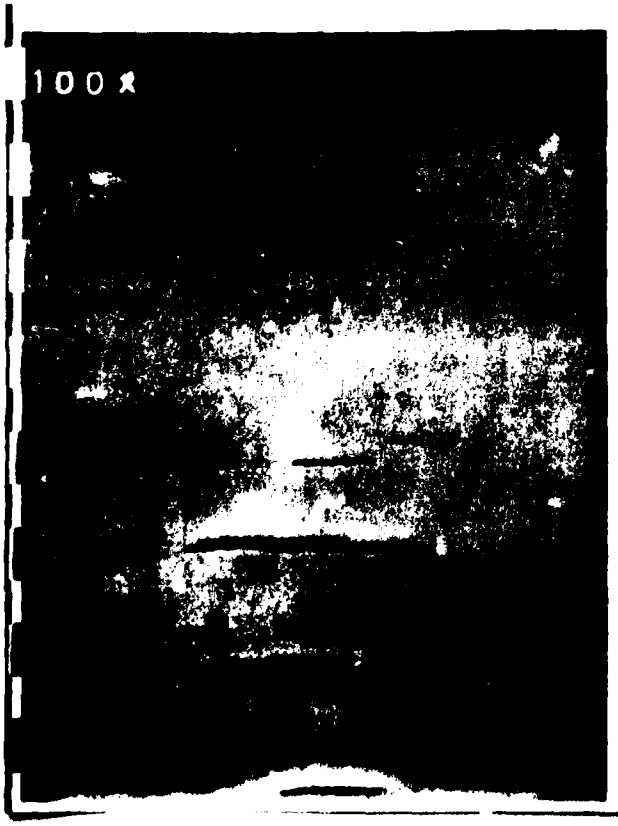
micron size 5 10 20 30
count 726 192 36 10

ferrograph DR L/S
2.8/1.6

spectro Fe Cu Al Si
ppm 5 3 0 6

ferrogram; normal, some debris and very few chunks.

#67 1800psi 3Hr.



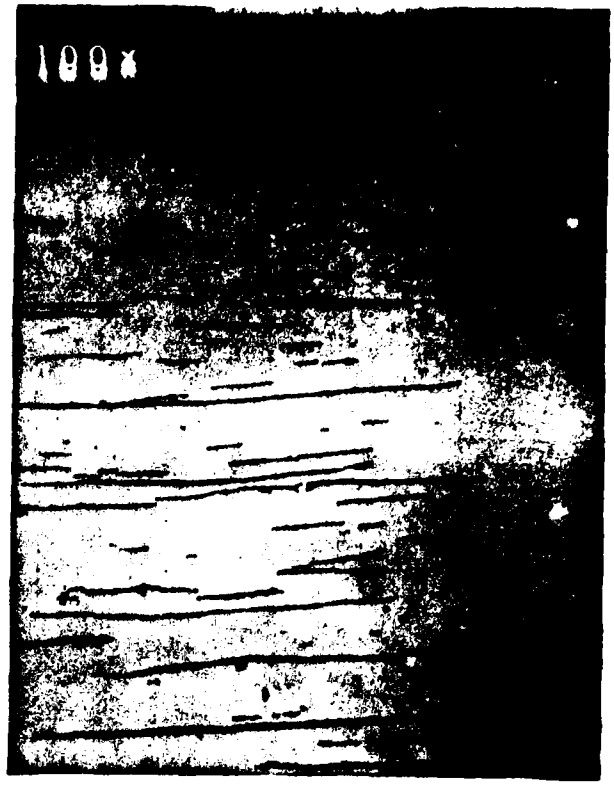
micron size 5 10 20 30
count 2420 614 93 26

ferrograph DR L/S
3.7/2.5

spectro Fe Cu Al Si
ppm 4 3 0 7

ferrogram; mostly normal, few larger than normal rubbing wear and square.

#69 2000psi 1Hr.



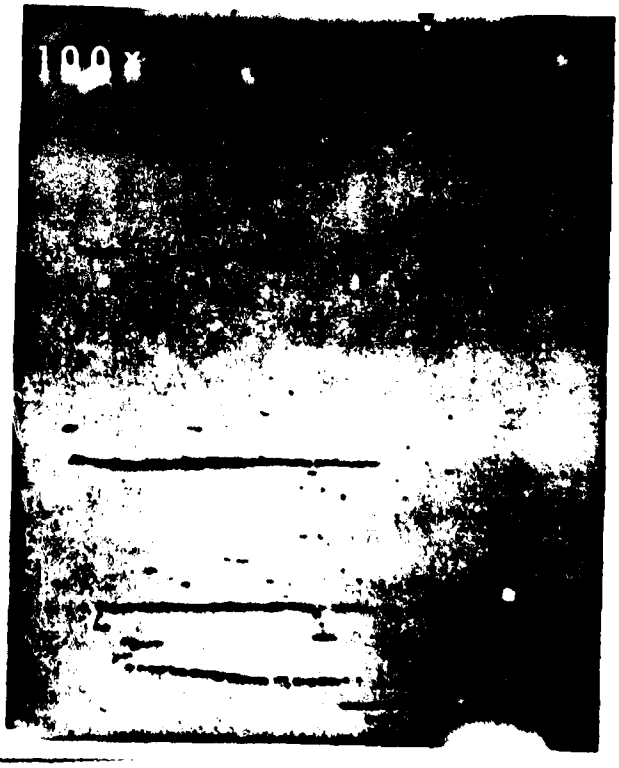
micron size 5 10 20 30
count 576 176 36 14

ferrograph DR L/S
3.7/2.3

spectro Fe Cu Al Si
ppm 5 3 0 7

ferrogram; normal.

#71 2000psi 2Hr.



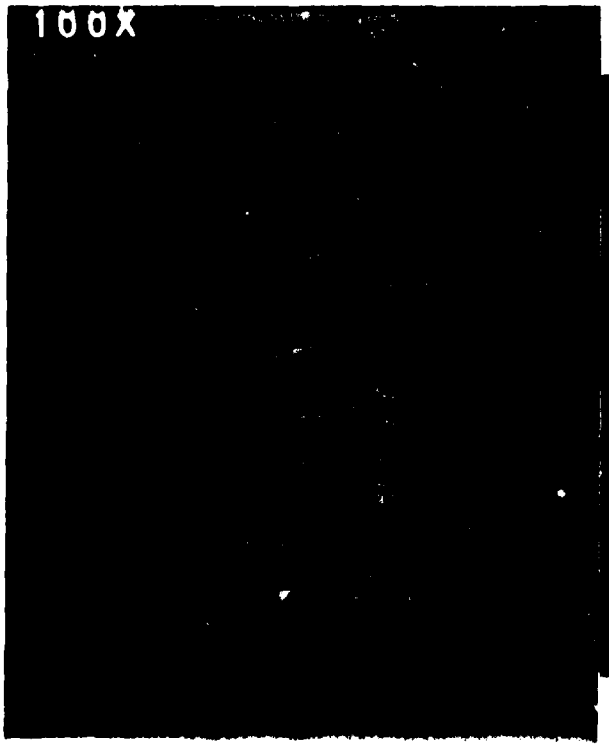
micron size 5 10 20 30
count 860 252 42 14

ferrograph DR L/S
2.3/1.7

spectro Fe Cu Al Si
ppm 6 4 0 9

ferrogram; normal some crystalline particles.

Summery of the outlet samples from pump 468F. The inlet samples were for the most part normal. There were some that had some larger wear particles, but these were few.



#73 2000psi 1Hr
micron size N.A.

ferrograph DR L/S
5.2/1.9

spectro Fe Cu Al Si
ppm 4 4 3 8

ferrogram: normal rubbing wear with heavy amount of spheres, some large.

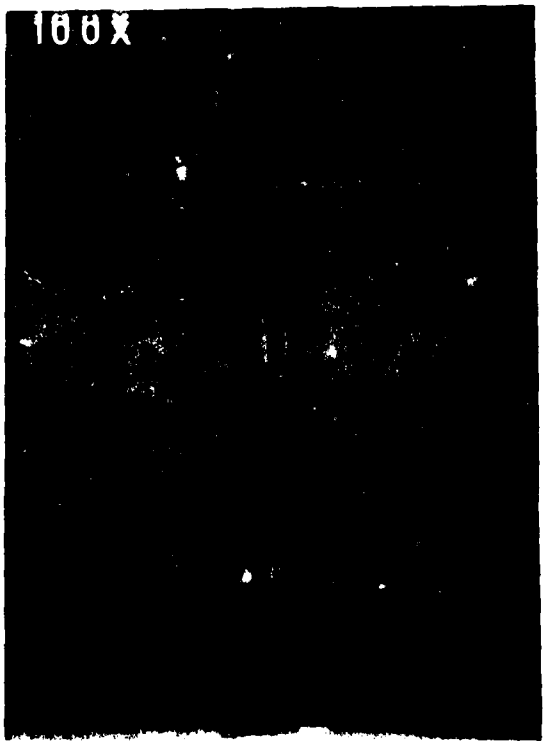
#75 2000 psi 2Hr.

micron size 5 10 20 30
2598 662 128 35

ferrograph DR L/S
5.3/2.1

spectro Fe Cu Al Si
ppm 4 4 3 13

ferrogram: normal rubbing wear with heavy amount of small spheres.



#77 2000psi 30hr.

microns size	5	10	20	30
	531	139	32	13

ferrograph DR L/S
3.1/1.4

spectro	Fe	Cu	Al	Si
ppm	4	2	3	7

ferrogram: normal rubbing wear with moderate amount of debris and heavy spheres 2-15u.

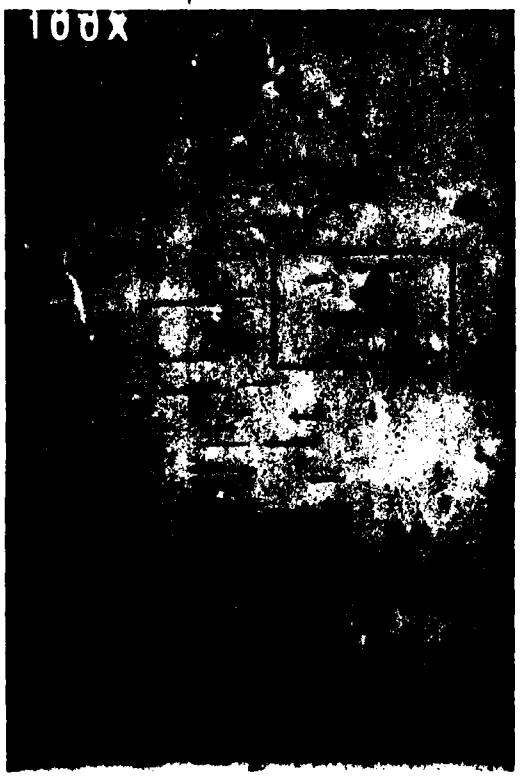
micron size	5	10	20	30
	448	134	34	9

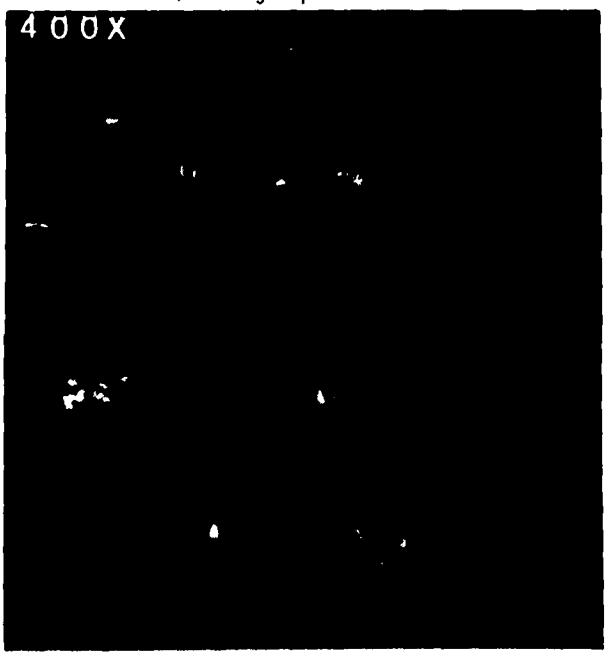
ferrograph DR L/S
4.2/2.4

spectro	Fe	Cu	Al	Si
ppm	4	2	3	5

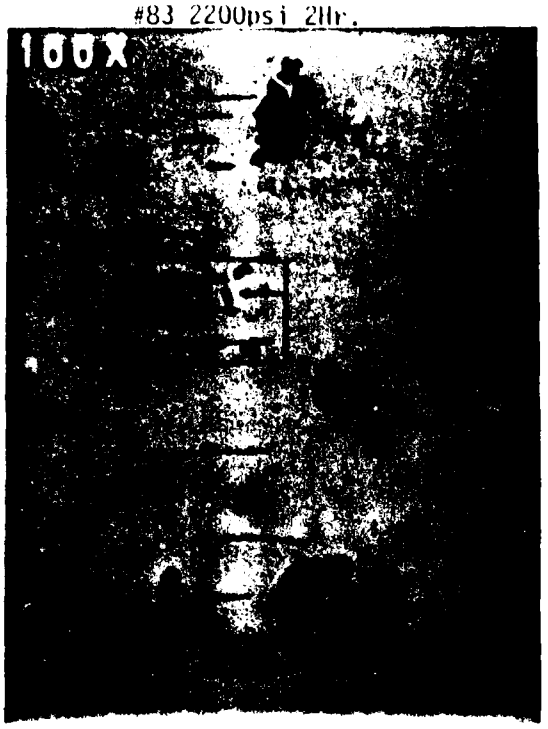
ferrogram; normal but a little larger than normal wear, heavy spheres.

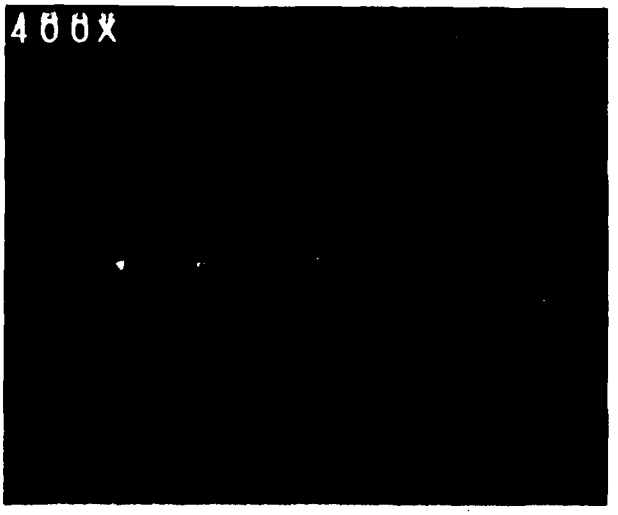
#79 2000psi 4Hr.





#83 2200psi 2Hr.





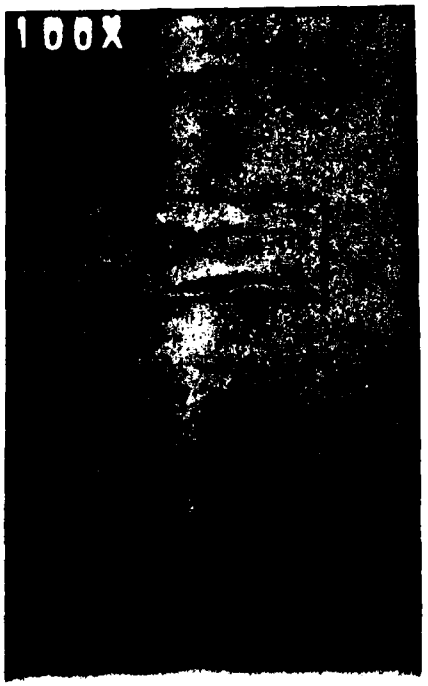
micron size 5 10 20 30
275 72 15 4

ferrograph DR L/S
2.6/1.5

spectro Fe Cu Al Si
ppm 4 2 3 7

ferrogram: normal rubbing wear with heavy spheres, most yet.

#85 2400psi 1Hr.



micron size 5 10 20 30
141 37 7 3

ferrograph DR L/S
3.0/1.7

spectro Fe Cu Al Si
ppm 4 2 3 6

ferrogram; normal rubbing wear with some cutting wear, spheres down from #83

81 2200psi 10hr

micron size - 5 10 20 30
369 114 29 11

ferrograph DP I/S
2.3/1.5

spectro Fe Cu Al Si
ppm 5 2 3 5

ferrogram: normal rubbing wear with a few non-ferrous chunks some brass. heavy spheres and heavy amount of large flat crys. debris.

#87 2400psi 2Hr.

micron size	5	10	20	30
	462	108	19	5

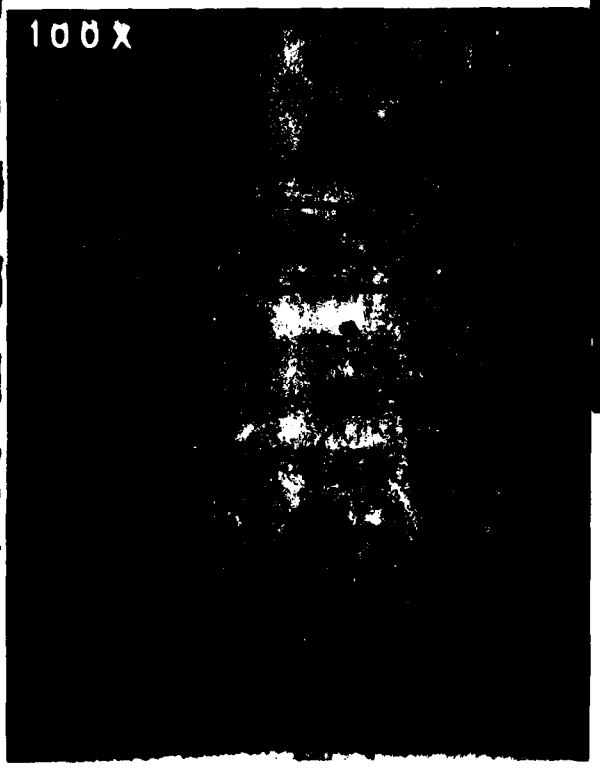
ferrograph DR L/S
1.7/1.2

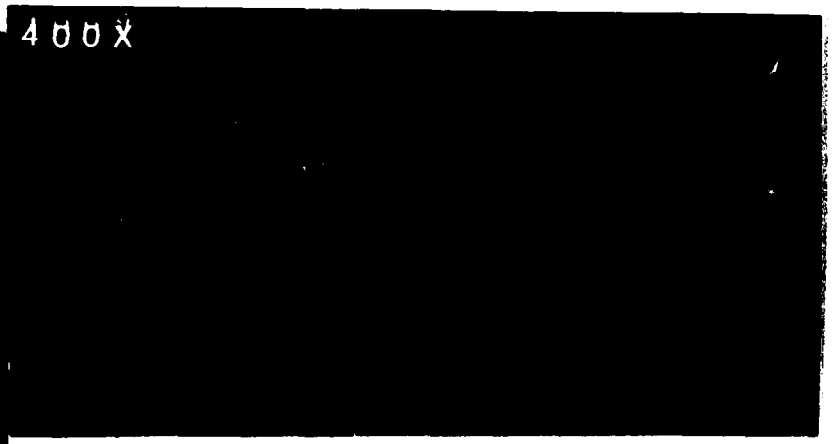
spectro	Fe	Cu	Al	Si
ppm	4	2	3	6

ferrogram: normal wear with small spheres.

#89 2400psi 3Hr.

micron size	5	10	20	30
	202	64	16	5

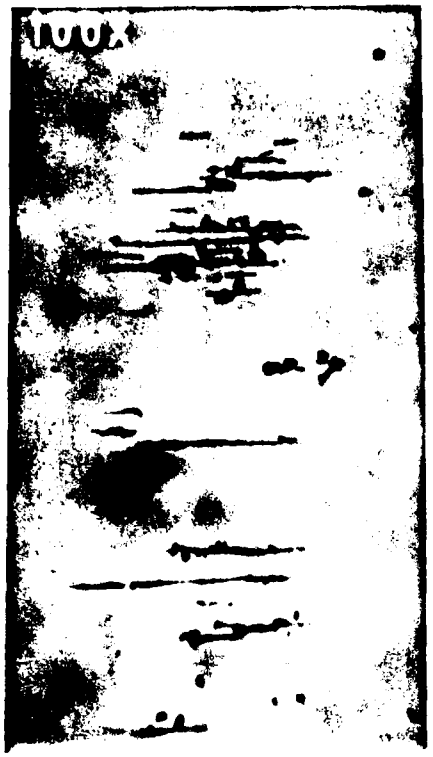




ferrograph DR L/S
2.6/2.4

spectro	Fe	Cu	Al	Si
ppm	5	2	2	6

ferrogram: some cutting wear with moderate debris and spheres.



#91 2600psi 1Hr.

micron size 5 10 20 30
383 110 23 8

ferrograph DR L/S
2.9/0.7

spectro Fe Cu Al Si
ppm 4 2 3 5

ferrogram: normal rubbing wear with some small chunks. spheres the same. some oxide.

#93 2600psi 2Hr.

micron size 5 10 20 30
277 90 15 6

ferrograph DR L/S
1.5/0.9

spectro Fe Cu Al Si
ppm 5 2 3 7

ferrogram: normal with little amount of spheres

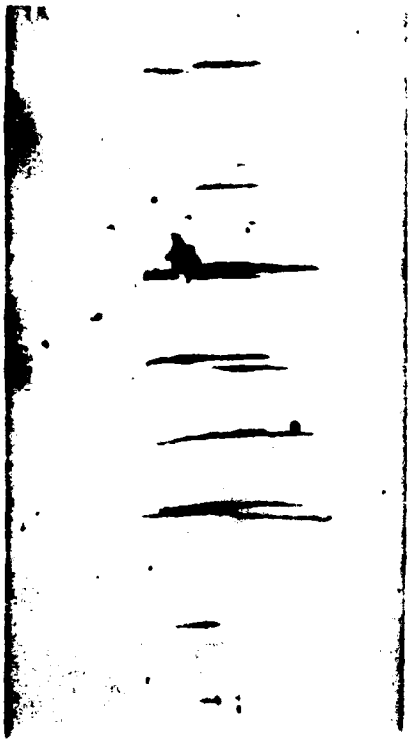
#95 2600psi 3Hr.

micron size 5 10 20 30
131 36 8 3

ferrograph DR L/S
9.0/1.6

spectro Fe Cu Al Si
ppm 3 2 2 5

ferrogram: normal wear with heavy spheres.



#97 2800psi 1Hr

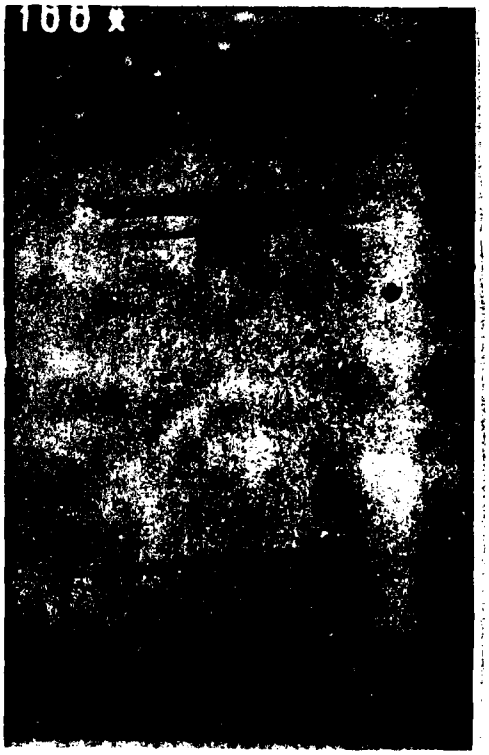
micron size 5 10 20 30
80 26 4 2

ferrograph DR L/S
3.5/1.8

spectro Fe Cu Al Si
ppm 4 2 3 6

ferrogram: normal little amount of spheres.

#101 3000psi 1Hr.

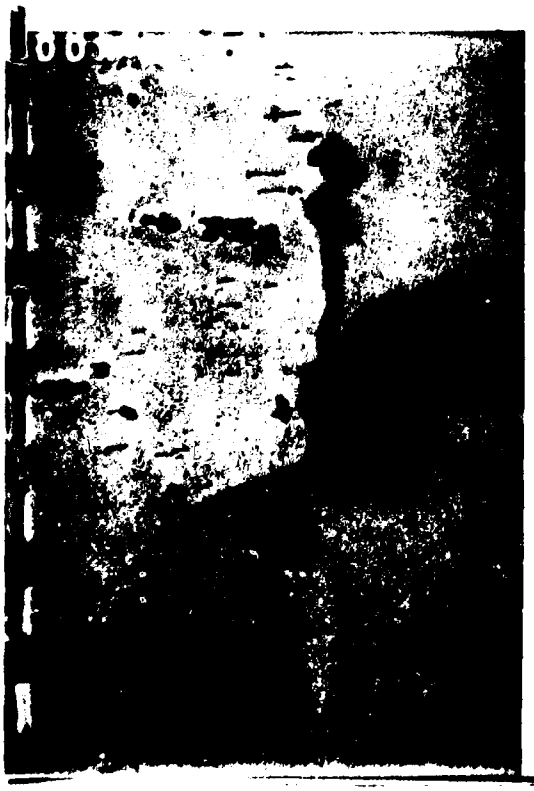


micron size 5 10 20 30
172 51 9 3

ferrograph DR L/S
2.8/1.2

spectro Fe Cu Al Si
ppm 5 2 3 5

ferrogram: normal simular to #97



#103 3000psi 2Hr.

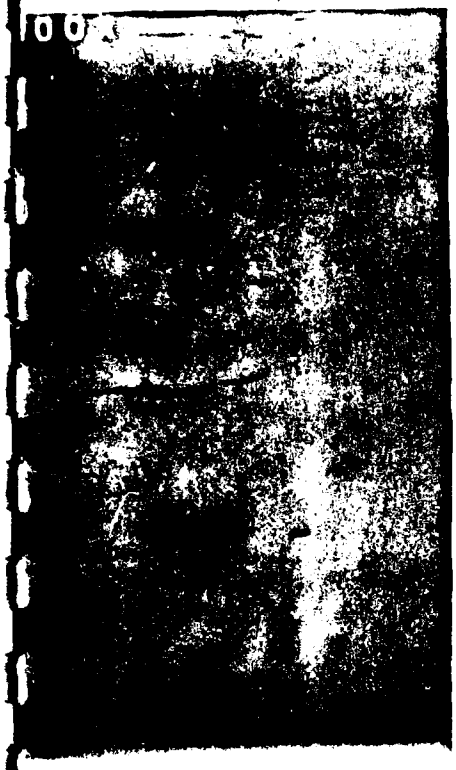
micron size 5 10 20 30
80 32 9 3

ferrograph DR L/S
1.5/0.8

spectro Fe Cu Al Si
ppm 4 2 3 7

ferrogram: some debris, normal wear with some large spheres.

#105 3000psi 3Hr.



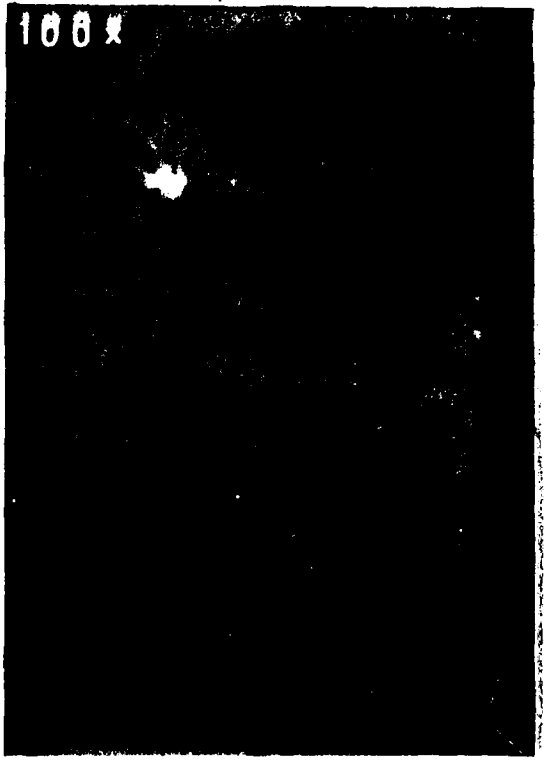
micron size 5 10 20 30
129 40 8 2

ferrograph DR L/S
2.2/1.8

spectro Fe Cu Al Si
ppm 4 2 3 6

ferrogram: simular to #103 but less debris.

#107 3000psi 4Hr.



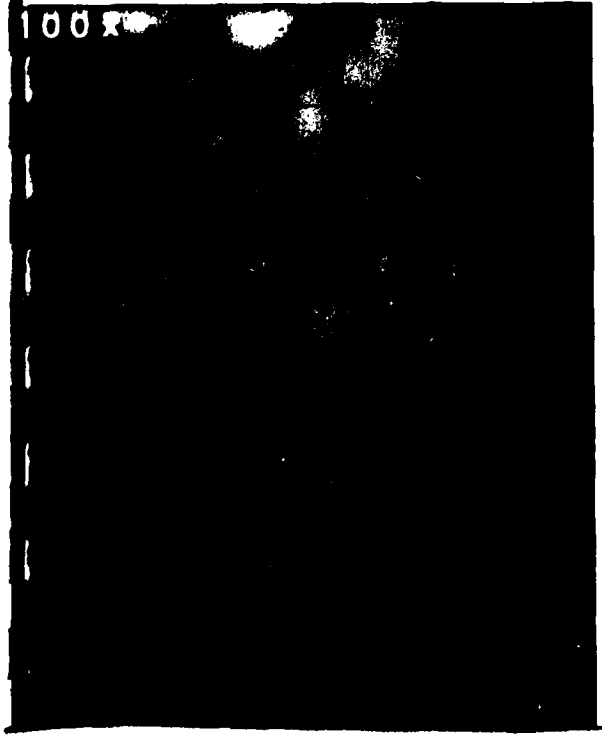
micron size 5 10 20 30
47 18 4 3

ferrograph DR L/S
3.1/0.9

spectro Fe Cu Al Si
ppm 4 2 3 6

ferrogram: normal but with
little cutting wear.

#109 3000psi 1A



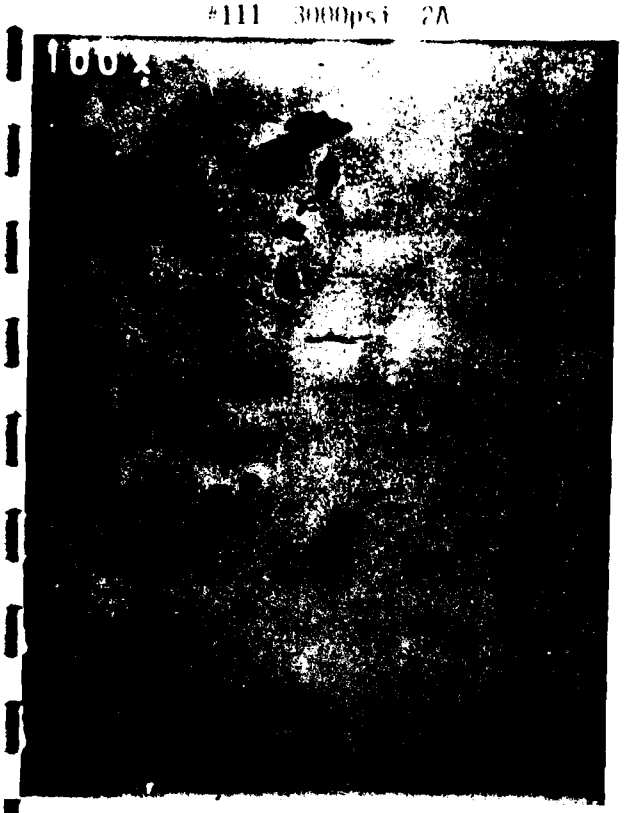
micron size 5 5 10 30
2194 2601 874 878

ferrograph DR L/S
1.2/1.0

spectro Fe Cu Al Si
ppm 4 2 3 7

ferrogram: normal wear with some small spheres,
very little cu.

#111 3000psi 2A



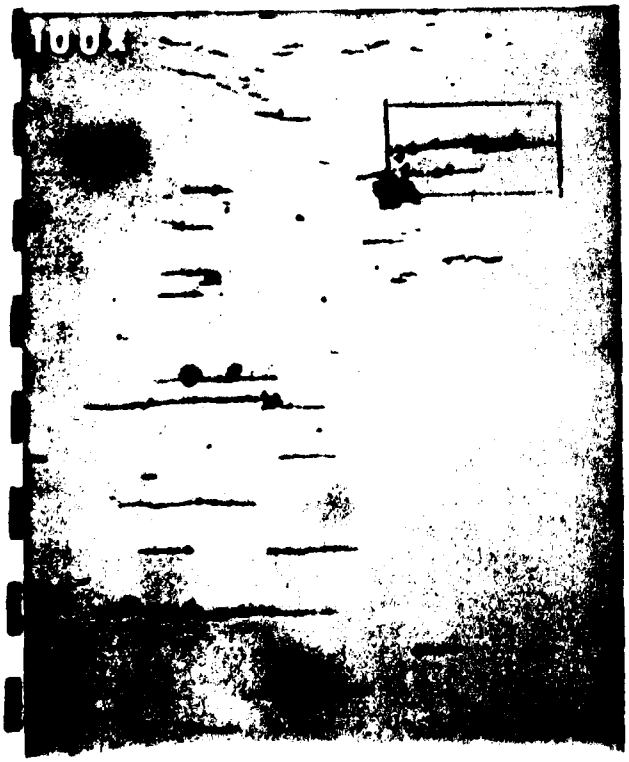
micron size 5 5 10 10 20 20
478 587 129 131 23 23

ferrograph DR L/S
1.8/1.0

spectro Fe Cu Al Si
ppm 3 2 3 5

ferrogram: normal wear with debris.

#113 3000psi 3A

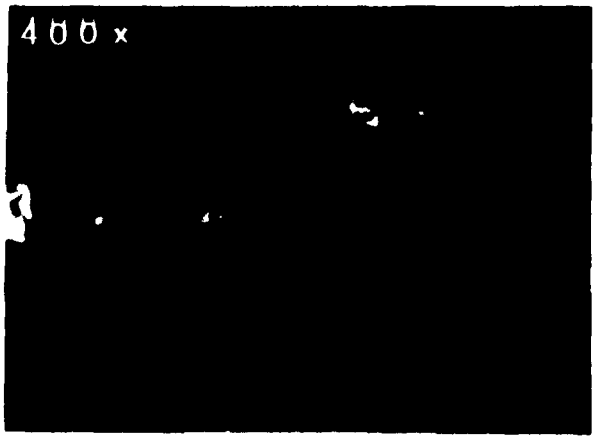


micron size 5 5 10 10 20 20
468 576 98 99 16 16

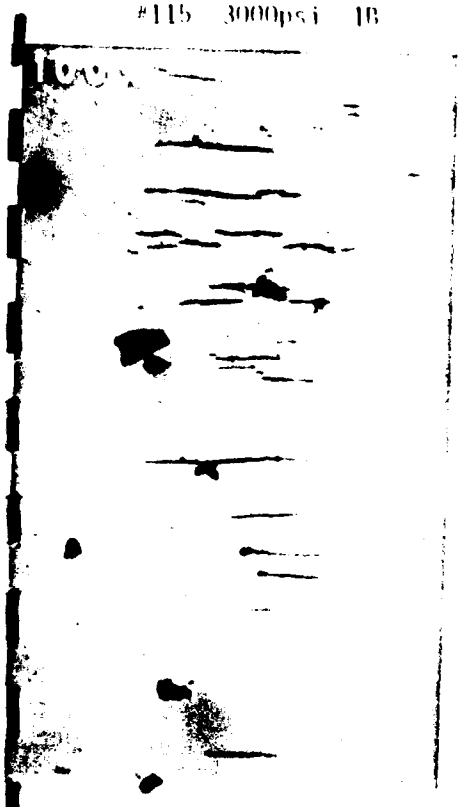
ferrograph DR L/S
2.5/1.6

spectro Fe Cu Al Si
ppm 5 2 3 7

ferrogram: larger than normal wear. very heavy amount of spheres.



#115 3000psi 1B



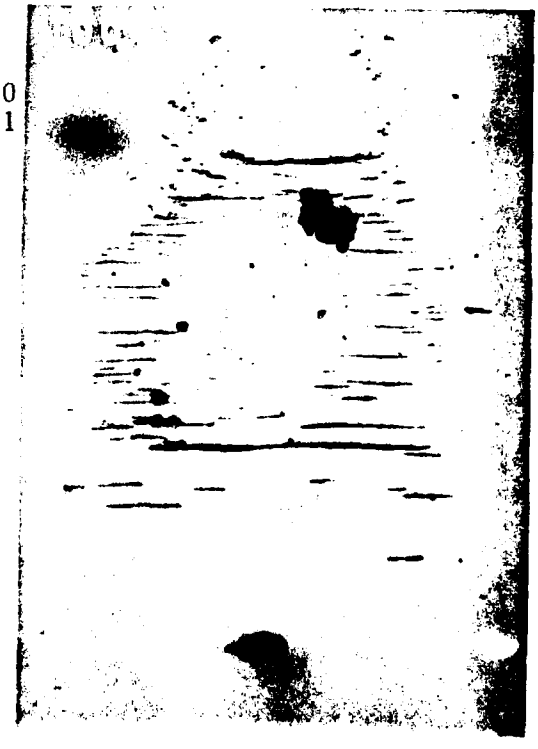
micron size 5 5 10 10 20 20
543 791 35 34 5 5

ferrograph DR L/S
5.8/4.7

spectro Fe Cu Al Si
ppm 4 3 2 7

ferrogram: normal wear with less spheres than #113.

#117 3000psi 2B



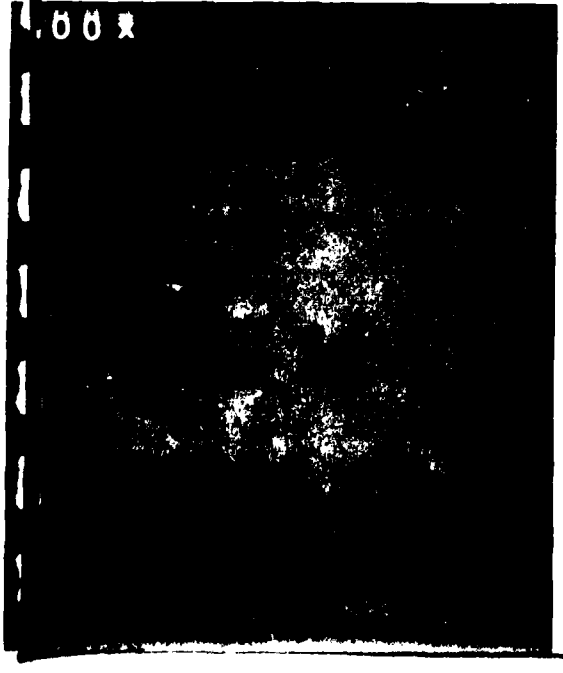
micron size 5 5 10 10 20
68 82 27 27 11

ferrograph DR L/S
N.A.

spectro Fe Cu Al Si
ppm 5 2 3 7

ferrogram: simular to #115

#119 3000psi 3B



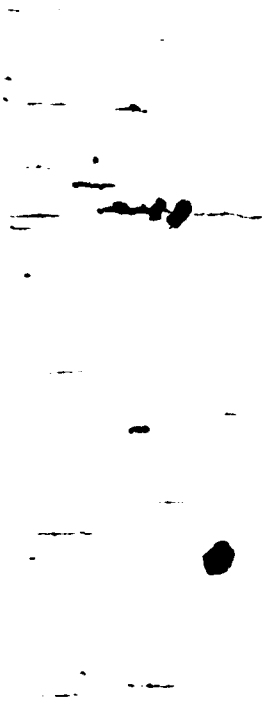
micron size 5 5 10 10 20 20
81 97 28 28 8 8

ferrograph DR L/S
2.6/1.5

spectro Fe Cu Al Si
ppm 5 2 3 7

ferrogram: normal wear with few spheres, some large debris.

121 3200psi 1Hr



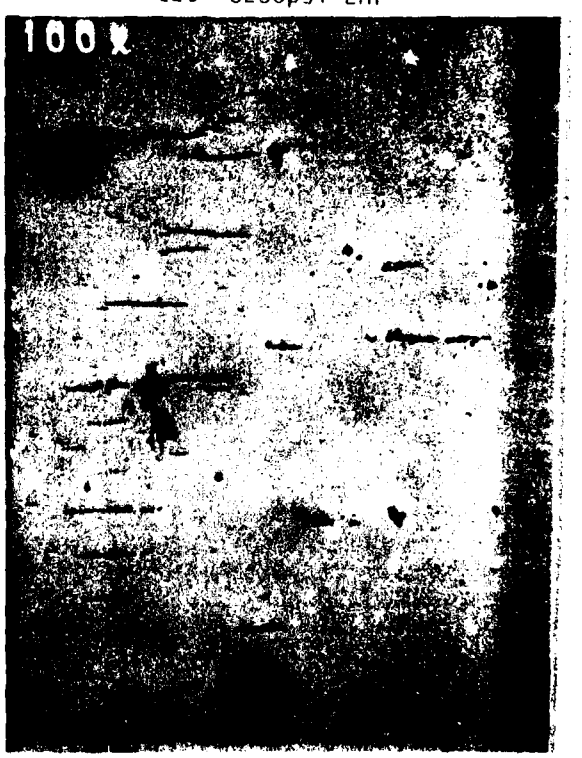
micron size 5 5 10 10 20 20
83 104 32 32 9 9

ferrograph DR L/S
1.3/1.2

spectro Fe Cu Al Si
ppm 4 2 3 6

ferrogram: normal wear with an increase in spheres.

#123 3200psi 2Hr



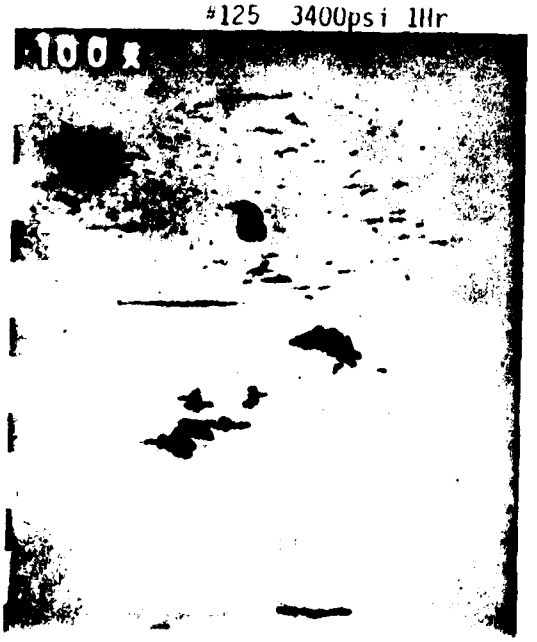
micron size 5 5 10 10 20 20
50 59 21 21 5 6

ferrograph DR L/S
2.5/1.5

spectro Fe Cu Al Si
ppm 4 2 3 6

ferrogram: normal wear,
increase in amount of spheres
from # 121.

#125 3400psi 1Hr



micron size 5 5 10 10 20 20
44 53 13 13 3 3

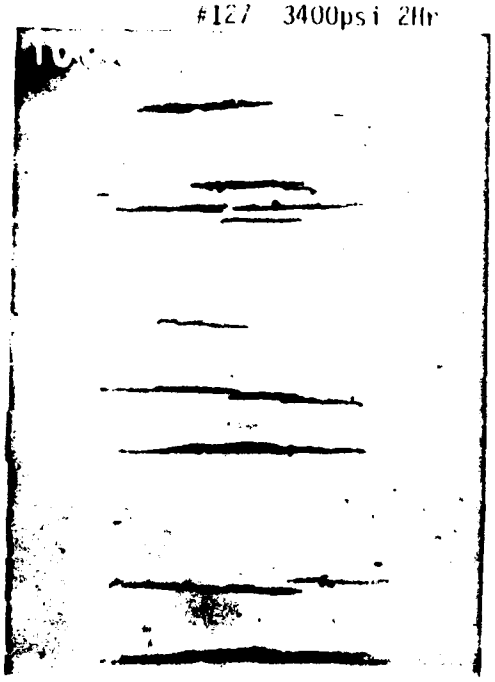
ferrograph DR L/S
1.6/0.9

spectro Fe Cu Al Si
ppm 3 2 3 7

ferrogram; normal with some large debris.

#123 using 10ml of sample.
400X at 40mm. brass was not seen in the normal sample of 3ml.

#127 3400psi 2Hr



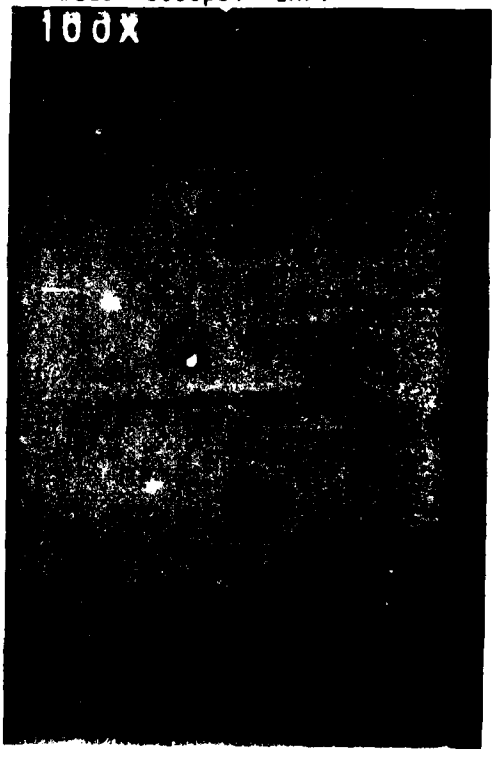
micron size 5 5 10 10 20 20
37 50 9 9 2 2

ferrograph DR L/S
2.2/1.3

spectro Fe Cu Al Si
ppm 4 2 2 5

ferrogram: normal wear with a moderate amount of spheres. increase from # 125

#129 3600psi 1Hr.



micron size 5 5 10 10 20 20
187 221 74 74 23 23

ferrograph DR L/S
4.0/2.9

spectro Fe Cu Al Si
ppm 4 2 2 6

ferrogram: normal wear decrease in spheres.

#131 3600psi 2Hr.

micron size 5 5 10 10 20 20
226 264 92 92 34 34

ferrograph DR L/S
5.0/3.1

spectro Fe Cu Al Si
ppm 4 2 2 6

ferrogram: few large wear particles.

#133 3600psi 3Hr.

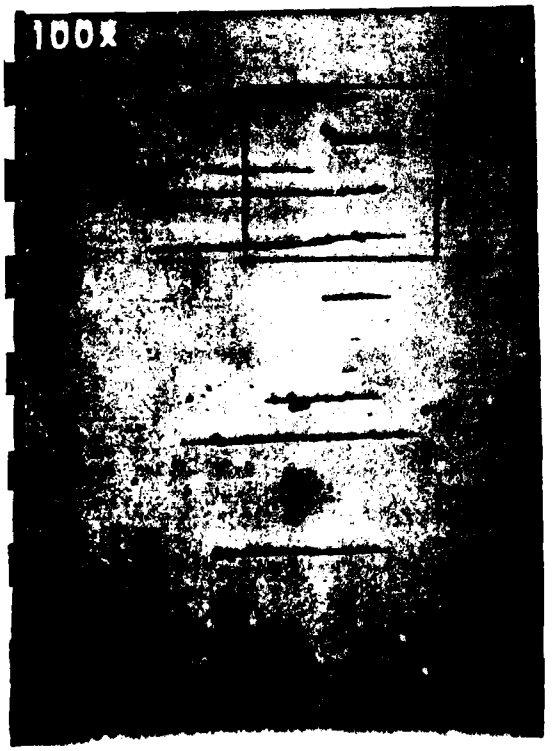
micron size 5 5 10 10 20 20
41 48 13 13 3 3

ferrograph DR L/S
1.2/0.7

spectro Fe Cu Al Si
ppm 4 2 3 6

ferrogram: very clean

#135 3800psi 1Hr.



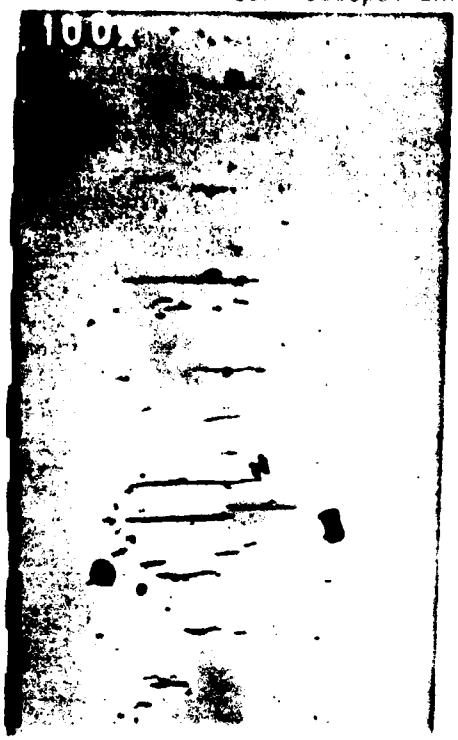
micron size 5 5 10 10 20 20
187 222 75 75 16 16

ferrograph DR L/S
3.1/2.4

spectro Fe Cu Al Si
ppm 4 2 2 6

ferrogram: some larger than normal wear, some cutting wear with non-ferrous chunks. moderate amount of debris.

#137 3800psi 2Hr.



micron size 5 5 10 10 20 20
289 353 109 110 32 32

ferrograph DR L/S
N.A.

spectro Fe Cu Al Si
ppm 4 2 2 6

ferrogram: normal wear, cleaner than #137.
few spheres.

#139 3800psi 3Hr.

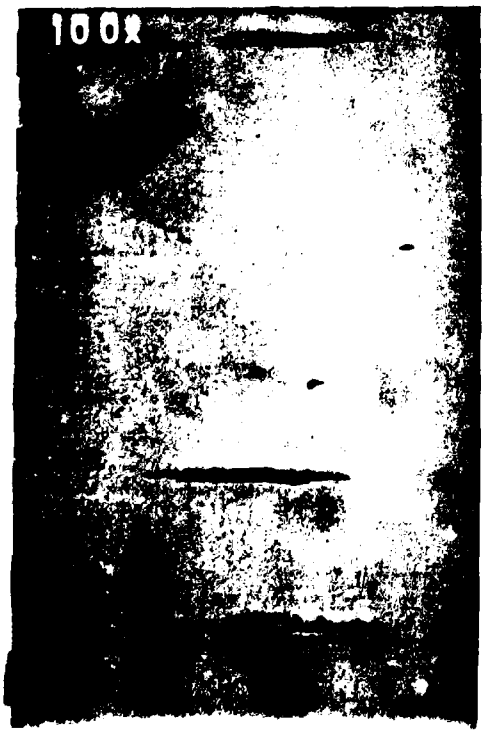
micron size 5 5 10 10 20 20
122 149 41 41 8 8

ferrograph DR L/S
N.A.

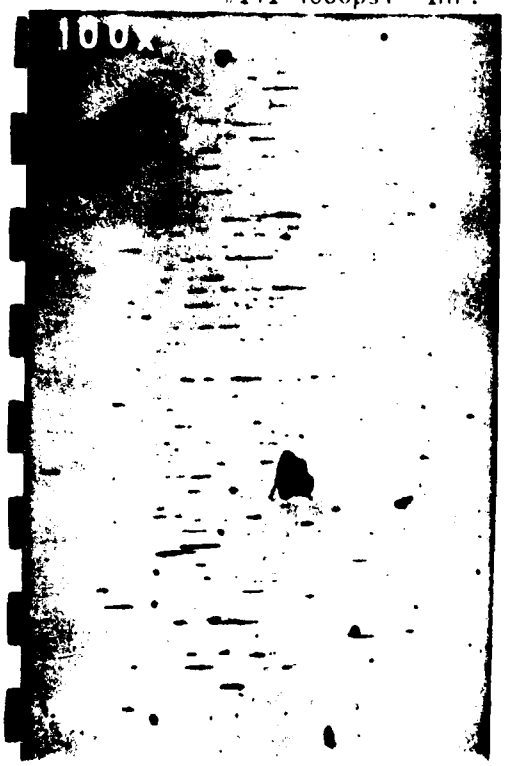
spectro Fe Cu Al Si
ppm 5 2 3 4

ferrogram: simular to #135, larger than normal wear with a moderate amount of debris.

#139 3800psi 3Hr.



#141 4000psi 1Hr.



micron size 5 5 10 10 20 20
105 122 40 40 10 10

ferrograph DR L/S
N.A.

spectro Fe Cu Al Si
ppm 4 2 3 7

ferrogram: normal wear with very few spheres.

#143 4000psi 2Hr.

micron size 5 5 10 10 20 20
137 163 52 52 12 12

ferrograph DR L/S
N.A.

spectro Fe Cu Al Si
ppm 3 2 3 5

ferrogram: clean. simular to #141

#145 4000psi 3Hr.

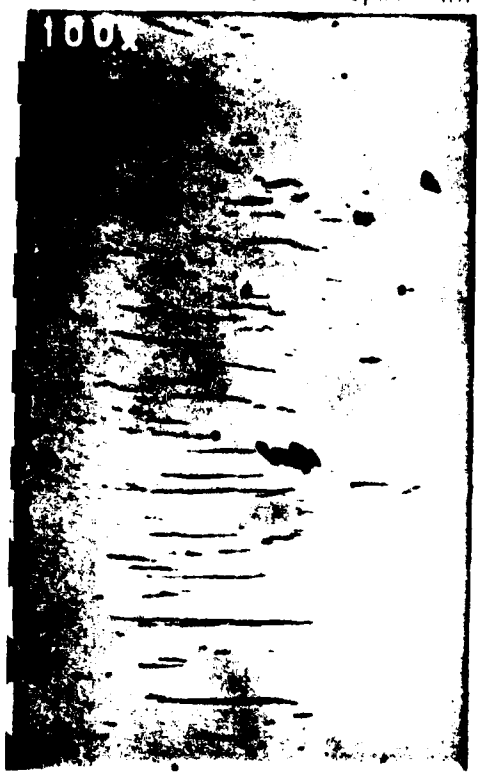
micron size 5 5 10 10 20 20
110 132 36 36 6 6

ferrograph DR L/S
N.A.

spectro Fe Cu Al Si
ppm 4 3 0 5

ferrogram: clean, normal wear.

#147 4000psi 4Hr.



micron size 5 5 10 10 20 20
142 171 53 53 15 15

ferrograph DR L/S
N.A.

spectro Fe Cu Al Si
ppm 4 2 2 7

ferrogram: clean, normal wear.

#149 4000psi 5Hr.

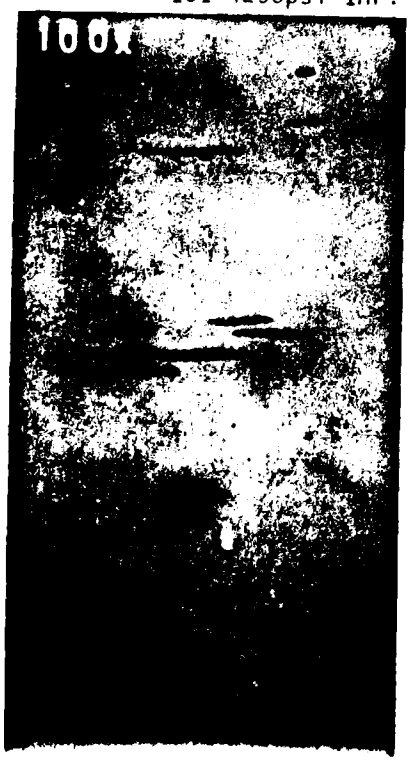
micron size 5 5 10 10 20
149 173 64 64 14

ferrograph DR L/S
N.A.

spectro Fe Cu Al Si
ppm 4 2 2 5

ferrogram: clean, normal wear

#151 4200psi 1Hr.



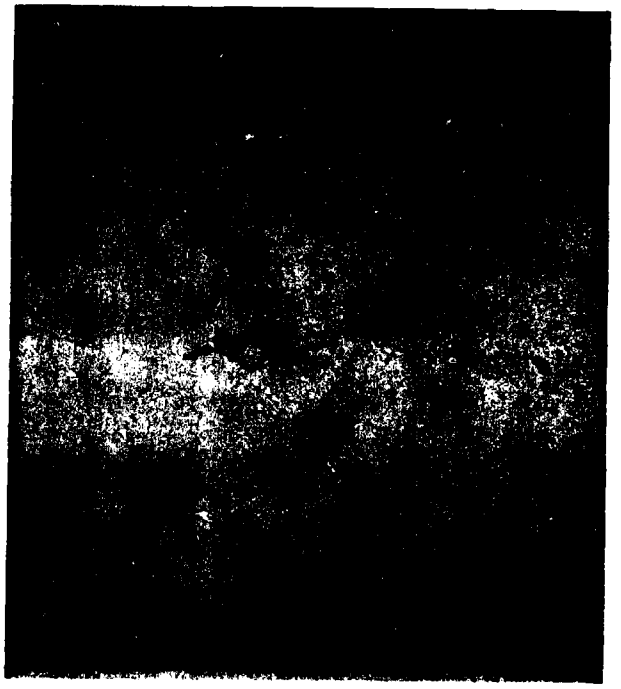
micron size 5 5 10 10 20 20
79 92 29 29 6 6

ferrograph DR L/S
N.A.

spectro Fe Cu Al Si
ppm 4 2 2 7

ferrogram: few larger than normal wear particles. few spheres.

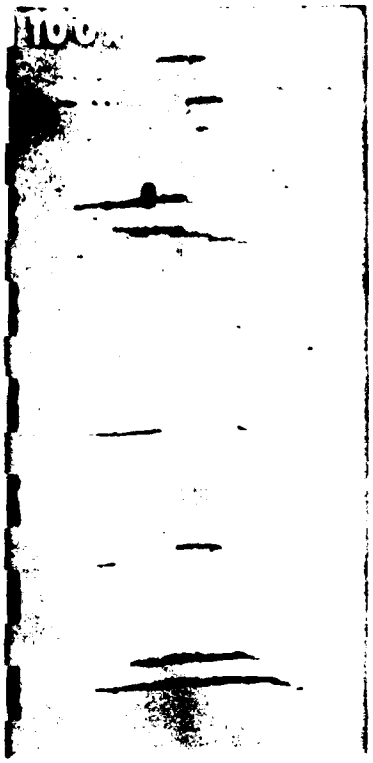
#153 using 30 ml of sample
100X entry. note the cutting wear.



#153 using 30ml
100X 53mm. more cutting wear

#153 using 30ml of sample
30mm. 400X large amount of non-ferrous wear metal.

#153 4200psi 2Hr.



micron size 5 5 10 10 20 20
254 291 107 107 34 34

spectro Fe Cu Al Si
ppm 5 2 0 7

ferrograph DR L/S
N.A.

ferrogram: normal wear with some debris.

#155 4200psi 3Hr.

micron size 5 5 10 10 20 20
336 390 144 145 37 37

ferrograph DR L/S
N.A.

spectro Fe Cu Al Si
ppm 4 2 0 7

ferrogram: normal wear with some debris.

#157 4200psi 4Hr.

micron size 5 5 10 10 20 20
135 158 57 57 15 15

ferrograph DR L/S
N.A.

spectro Fe Cu Al Si
ppm 3 2 0 5

ferrogram: normal wear.

#159 4400psi 1Hr.

micron size 5 5 10 10 20 20
301 349 135 136 39 40

ferrograph DR L/S
N.A.

spectro Fe Cu Al Si
ppm 4 2 0 7

ferrogram: normal wear

#161 4400psi 2Hr.

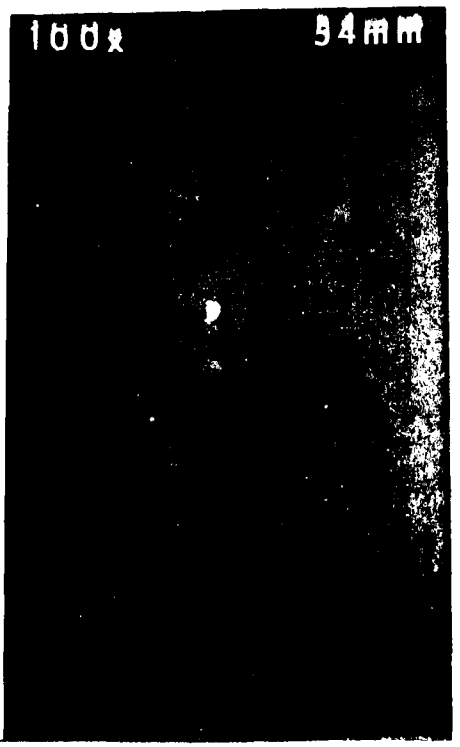
micron size 5 5 10 10 20 20
144 169 61 61 18 18

ferrograph DR L/S
N.A.

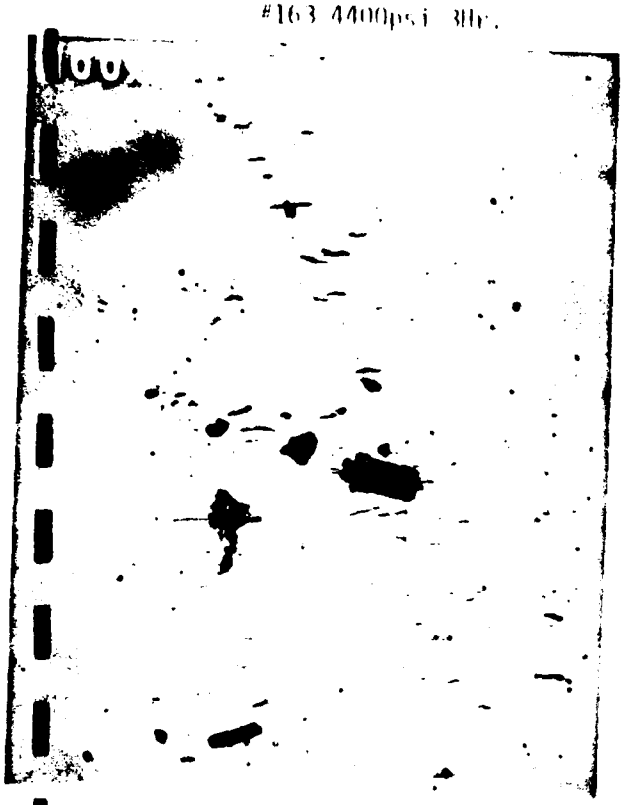
spectro Fe Cu Al Si
ppm 4 2 0 7

ferrogram: mostly normal with some cutting wear.

#161 4400psi 2Hr.



#163 4400psi 8Hr.



micron size 5 5 10 10 20 20
127 150 51 51 12 12

ferrograph DR L/S
N.A.

spectro Fe Cu Al Si
ppm 4 2 0 7

ferrogram: fairly clean, normal wear.

#165 4600psi 1Hr.

micron size 5 5 10 10 20 20
150 175 72 73 26 26

ferrograph DR L/S
N.A.

spectro Fe Cu Al Si
ppm 4 2 2 7

ferrogram: clean, normal wear

#167 4600psi 2Hr.

micron size 5 5 10 10 20 20
165 187 79 79 23 23

ferrograph DR L/S
N.A.

spectro Fe Cu Al Si
ppm 4 2 2 7

ferrogram: clean, normal wear.

END

DATE
FILMED
11-84

DTIC